SCIENCE FOR THE YOUNG

FORCE

BY

JACOB ABBOTT

SCIENCE FOR THE YOUNG;

OR,

THE FUNDAMENTAL PRINCIPLES OF MODERN PHILOSOPHY
EXPLAINED AND ILLUSTRATED

IN

CONVERSATIONS AND EXPERIMENTS,

AND IN

NARRATIVES OF TRAVEL AND ADVENTURE BY YOUNG
PERSONS IN PURSUIT OF KNOWLEDGE.

VOL. IV.—FORCE.

LAWRENCE'S SEAT.

SCIENCE FOR THE YOUNG.

FORCE.

BY JACOB ABBOTT,

AUTHOR OF

"THE FRANCONIA STORIES," "MARCO PAUL SERIES," "YOUNG
CHRISTIAN SERIES," "HARPER'S STORY BOOKS,"
"ABBOTT'S ILLUSTRATED HISTORIES," &c.

WITH NUMEROUS ENGRAVINGS.

NEW YORK:
HARPER & BROTHERS, PUBLISHERS,
FRANKLIN SQUARE.

OBJECT OF THE WORK.

The object of this series, though it has been prepared with special reference to the young, and is written to a considerable extent in a narrative form, is not mainly to amuse the readers with the interest of incident and adventure, nor even to entertain them with accounts of curious or wonderful phenomena, but to give to those who, though perhaps still young, have attained, in respect to their powers of observation and reflection, to a certain degree of development, some substantial and thorough instruction in respect to the fundamental principles of the sciences treated of in the several volumes. The pleasure, therefore, which the readers of these pages will derive from the perusal of them, so far as the object which the author has in view is attained, will be that of understanding principles which will be in some respects new to them, and which it will often require careful attention on their part fully to comprehend, and of perceiving subsequently by means of these principles the import and significance of phenomena occurring around them which had before been mysterious or unmeaning.

In the preparation of the volumes the author has been greatly indebted to the works of recent European, and especially French writers, both for the clear and succinct expositions they have given of the results of modern investigations and discoveries, and also for the designs and engravings with which they have illustrated them.

CONTENTS.

ILLUSTRATIONS.

FORCE.

10246

CHAPTER I.

RICK VAN DORN.

"JOHN," said Lawrence one day, when John was with him in the shop watching some work at the lathe in which he was engaged, "are there any bad boys in your school?"

"Two or three," said John.

"Is there any one that is really ugly," continued Lawrence, "so that every body dislikes him? I want a really ugly boy."

"There's Rick Van Dorn," said John. "He's ugly enough. But what do you want of an ugly boy?"

"I wish to try some experiments upon him," said Lawrence.

"Oh ho!" exclaimed John. "What an idea! You can't try experiments upon a boy."

"I want to see, at any rate, whether I can or not," said Lawrence. "How old a boy is Rick, as you call him?"

"About twelve or fourteen," said John.

"How came he by such a name as Rick?" asked Lawrence.

"I don't know," replied John. "His real name may be Richard, for aught I know. But the boys always call him Rick."

"Is he a handsome boy?" asked Lawrence.

"No," said John. "He looks as cross and ugly as he *is.* All the boys despise him and hate him. Besides, he is the poorest scholar in school. He don't study any, and he is always in some mischief or other."

"Doesn't he do *any thing* well?" asked Lawrence.

"He plays ball pretty well," said John. "Yes, he's a good ball-player. They all like to have him on their side in playing ball, and I don't believe but that he might do well in other things if he only would try; but he won't try."

"Well, couldn't you ask him to come here and see me some day?" said Lawrence.

"He wouldn't come if I should ask him," replied John.

"Why not?" asked Lawrence.

"He would think that you had some design upon him," said John. "He is very suspicious when any body sends for him. He thinks, I suppose, that he is going to get a scolding for some of his misdeeds."

"Tell him," said Lawrence, "that I have got a lathe, and am going to turn a bat, and that I want him to come and tell me about the best size and shape of it."

"He may possibly come for that," said John, musingly; "but he is more likely to think that it is only a pretense—to catch him."

"Well, I must confess he would not be far from right in that supposition," said Lawrence. "But you can ask him, at any rate. Ask him to come next Saturday forenoon."

"Well," said John, "I'll ask him, though it is very doubtful whether he will come. But what do you really want him for, any how?"

"I want to try an experiment upon him. I'm going to try to reform him."

"To reform him!" repeated John. "I'm sure you won't succeed. Every thing has been tried already and failed. I should like to know by what means you expect to reform him."

"By means of force," said Lawrence, quietly.

"Force! Hoh!" exclaimed John, much surprised. "I don't think you have any authority to use force upon him. Besides, he won't stay. And then force has been used. He says that if there was any virtue in whipping to make a good boy, he should have been a saint before this time, for he has had nothing but whippings all his life."

"I did not express myself quite right," said Lawrence. "It is not force itself exactly, but ideas of force that I mean to employ. But you persuade him to come, and I'll try my experiment; and I'll explain to you, in the end, how it worked."

And here it must be said that there is one thing curious in respect to our ideas of every thing pertaining to the external world, and that is, that we can not, strictly speaking, form any conception of what any thing *really is*, in its intrinsic and real essence, but only *how it acts.*

To show what I mean by this, let us take the case of lead as an example. We say that lead is heavy. We mean by that that when we let it rest upon our hand, or upon any movable support, it weighs it down; that is, it *acts* in a certain way. We say it is malleable; we mean nothing more by that than that when it is struck by any hard substance it yields, and becomes indented or flattened. It is fusible, which is only a word expressing how it acts when heated to a certain degree, namely, it sinks down from its

LIQUEFACTION.

solid state and gradually becomes liquid. When we say it is of a bluish color, we mean simply that when it is held before our eyes it sends rays of light into them which produce in our minds a particular sensation. It is the same with all the other properties of lead. The names of these properties are only expressions of the *manner in which the substance acts* under different specified circumstances.

As to the substance itself in its intrinsic and absolute nature we can have no idea whatever.

Now it is not only so with lead and other metals, but with all the material substances, and all the agencies and powers of nature of every kind. What we call *force* forms no exception to this universal rule. There is something in its inner and intrinsic nature that entirely eludes the efforts of the wisest philosophers to comprehend. All that we can really learn about it is how it acts. The young persons, therefore, who may read this book, must give up all idea of obtaining from it any conception of what force, in its hidden nature, is, and only hope to learn in what different forms it presents itself to us, and in what ways it acts in those different forms.

And so Lawrence, in saying that he was going to try to interest Rick Van Dorn in ideas of force, meant only that he intended to try to interest his mind in certain new trains of thought in respect to the different forms of force, and its various modes of action, and not at all in relation to its internal and absolute nature.

The fact was, that Lawrence had become so accustomed, in his scientific studies, to consider all the substances and agencies in nature as governed by fixed laws, so that the way to change the action of any one of them was to change the circumstances under which it was placed, and not to get out of patience and fret at the wrong action—as, for example, if he was trying to melt lead, and it would not melt as fast as he expected, not to denounce or find fault with the lead, but simply and quietly to give it more time, or apply more heat—he had become so accustomed, I say, to act on these principles in dealing with material agencies, that he was quite inclined to look upon mental and moral processes in somewhat the same light. Or, rather, he was inclined to consider and inquire whether there might not be something analogous in the phenomena of mind to the regularity of sequence, in respect to cause and effect, that he knew so certainly every where prevailed in the world of matter.

There can be no doubt, I think, that there is some truth in this view of the subject, and that we should all act more philosophically, and get on much better, in dealing with the wrong doing that we witness around us in the world, if we would scold and fret about it less, and be less inclined to be made indignant by it, and try more to devise means for changing the influences that have been or are now operating upon those that act badly.

But we must return to Lawrence and John.

"But really," said John, after a short pause, what kind of an experiment is it that you are going to try on Rick?"

"I can't explain it very well," said Lawrence, "till after I have tried it. But I'll tell you a little story which perhaps you may think will throw some light upon it."

So Lawrence began his story as follows:

"There was once a farmer who was worried and plagued almost to death by a swampy place on his meadow. There was a little rill of water which came down from a spring on the upland, and, instead of finding a natural channel by which it could flow off into the river, it spread all over the ground in a certain spot, and killed out all the healthy grass, and caused hummocks of wild grass and weeds to grow in its place. It made the ground so soft and boggy that the farmer sank into it over his shoes, even when he went near the margin of it; and his cattle often got mired in it. The farmer used to fret and scold every time he came that way, saying, 'Confound the vile brook!'

"At one time he conceived the idea of curing the mischief, by stopping the water from coming into the meadow by a dam. So he hauled a great log across the little rill where it came down from the upland, and by packing sods against the upper side of the log he made quite a good dam. But of course the dam soon got full, the water ran over the top of the log, or, insinuating itself among the sods, oozed through, and soon made the matter worse than before. Then he tried another dam a little farther up, and afterward another a little farther down, but all to no effect."

"What a silly man!" said John.

"He used to complain in an impatient and fretful way to his wife and to his neighbors about the plaguy brook," continued Lawrence. "It was the torment of his life," he said. He did not dare even to let his children go into the field for fear that they should get swamped in that quagmire.

"At last one of his neighbors went with him to look at the place.

"'Why, man,' said his neighbor, 'you don't go to work in the right way. You must not fight the mischief by damming up the flow of the water, but you must open a channel for it in a safe place where it will do no mischief.'

"So his neighbor helped him to tear away one of the little dikes which he had made on one side, to prevent the water from spreading over a new place in the meadow, and dug a channel in the ground where the dam had been. They continued this channel down through the part of the ground most favorable till they reached the river. As soon as they had done this, the water began to flow freely through it. The farmer and his neighbor looked at the little rill a few minutes, and then the farmer turned toward the swampy place and said, 'It doesn't do a bit of good. The ground there is just as miry, and the grass as coarse and good for nothing as ever.'

"'My dear man,' said the neighbor, 'do you expect the mischief that has been years in growing can be repaired in an hour? Wait three months and then see.'

"The farmer waited three months, and by that time the aspect of things had entirely changed. The swampy place had become of itself dry and hard, and the cultivated grasses, good for hay, had spread all over it again, and the water flowed quietly down toward the river through a pretty winding channel over a sandy bottom, and between banks of flowers, where the farmer's children used to like to come often to play."

Lawrence paused as if he had finished his story. John also paused a moment or two, as if he were thinking of it.

"It is a very good story," he said at length, "though I don't see what it has to do with your plan about Rick Van Dorn. You said it would throw some light on that subject."

"I said perhaps you *would think* that it threw some light on that subject," said Lawrence.

"I don't think it does," said John. "At least I don't see any light."

"Then I was mistaken," said Lawrence.

CHAPTER II.

CRANK MOTION.

LAWRENCE and John were at a town in New England, near the sources of the Connecticut River, where Lawrence was pursuing some scientific studies connected with his profession of civil engineer, and John was receiving instruction at a certain institution in the vicinity, known as the Morningside school, at the time when the conversation described in the preceding chapter took place.

Lawrence had fitted himself up a shop, where he had a bench and tools, and also a lathe, and where he was accustomed to work at leisure times, making apparatus of various kinds for his investigations and experiments. It was to this shop that he invited Rick to come.

On the Saturday following the conversation narrated in the last chapter, John came into the shop where Lawrence was at work, and said that Rick had come to the gate, but would not come in.

"Why won't he come in?" asked Lawrence.

"I don't know," replied John. "He seems to think that you have some design upon him."

So Lawrence went out to the door and called to Rick.

"Rick," said he, "come in here."

"What do you want of me?" asked Rick.

"I want you to give me some advice about making a bat," said Lawrence.

Rick, who was standing just outside of a gateway, with his hand upon the gate, as if ready to start off at the least alarm, looked curiously upon Lawrence for a moment, and then said, "Upon honor?"

"Yes," said Lawrence, "upon honor."

"You have got some secret design upon me, I believe," said Rick.

"That's a fact," said Lawrence; "I have."

Rick looked up surprised.

"What is it?" said he.

"To make you my friend," replied Lawrence, "so that you will come here often and help me."

Rick looked surprised and puzzled. He gazed a moment at Lawrence as if uncertain what to do, and then, as if won by Lawrence's frank and open expression of countenance, and his honest and friendly manner, he came slowly toward him and entered the shop.

He and Lawrence had, however, scarcely entered the shop before a messenger came from the house to say that some visitors had called, and Lawrence and John were requested to go in and see them. So Lawrence asked Rick to excuse him for a few minutes.

"You can amuse yourself," said he, "in looking about the shop while we are gone, and seeing the tools and things."

So Lawrence and John went away. As they were going along the passage-way that led into the house, John said to Lawrence,

"I don't think much of your sense in leaving such a boy as Rick among your nice tools."

"Why—what will he do?" asked Lawrence.

"Oh, he'll do some mischief or other," replied John. "He'll break something, or dull some tool, or play some trick or other."

"I hope he will," said Lawrence.

"Hope he will!" exclaimed John, surprised. "Why do you hope he will?"

"Because then I shall know that he is really the kind of boy that I want to experiment upon," said Lawrence.

Lawrence's wishes, thus expressed, were not, however, after all, exactly realized, for Rick, when left alone in the shop, did not undertake to do any actually malicious mischief, though he met with a mishap which for a moment greatly alarmed him. It happened that there was a grindstone in the corner of Lawrence's shop which was turned by means of what is called a *treadle.* Such a treadle consists of a wooden bar placed near the ground parallel to the frame of the grindstone. The end which is farthest from the grinder when the stone is in use is pivoted to the frame by means of a wooden pin, and to the middle of it is attached an iron rod which extends upward, and by means of a hook at the upper end clasps a small crank formed upon the axle of the grindstone, while the other end extends forward near the place where the grinder stands. By this contrivance the grinder, working this outer end of the bar with his foot, can turn the grindstone himself, while holding the tool with his hands, so as to obviate the necessity of having two persons to do the work.

Now Rick, in seeing this grindstone standing in the corner, went to it, and, as idle boys are always very prone to do in such cases, began turning it around by means of the treadle, by way of amusing himself, to see how fast he could make it spin.

So he began to work the treadle with his foot, bearing hard upon the outer end of it with his whole weight every time the crank came round, thus imparting to it a rapidly increasing motion. In a short time the heavy stone was brought into a state of very swift rotation, and it revolved, moreover, with so much power that the crank, in turning, would lift the outer end of the treadle-bar so forcibly as to lift Rick off the ground when he rested his weight upon it, and give him what he called a ride. But the fun, as Rick called it, was soon brought to a very unexpected termination by something suddenly giving way. The treadle-bar flew out of its place, the connecting rod became separated, and the different parts flew about in the most violent and alarming manner as the stone went whirling round with great apparent momentum. Rick was aghast with surprise and alarm. He seized hold of the stone and tried to stop its motion. But all his efforts were vain. It went furiously on, and seemed to be rattling and smashing every thing to pieces.

It was just at this crisis that Lawrence and John came back into the shop. Rick was much alarmed. He looked up toward Lawrence as he saw him coming in, and said,

"Dear me! I've done some dreadful mischief!"

"Oh no!" said Lawrence. "You may have done some damage, but I do not believe you have done any *mischief*. Mischief is harm done intentionally, and I am sure you can not have intended to do any harm to my things."

Rick said that he would not do damage on purpose on any account.

Lawrence then went to examine the grindstone, and after looking at it a moment as it gradually ceased its motion and came to a stand-still, he said,

"You have not even done any damage—at least, none of any consequence. There was only a pin that came out. It ought to have been fastened in more securely."

Rick was quite reassured by hearing Lawrence speak of the damage which he had done in this way, and began at once to help Lawrence to repair it. The pin that had come out was in the farther end of the treadle-bar, and was the pivot on which that end turned in working the treadle, so as to cause the grindstone to revolve.

"You have not only not done any damage," said Lawrence, but you have performed an experiment that illustrates a very fundamental principle in respect to the nature of force. I will explain the principle to you, and if you and John understand it, and remember it, you will gain a great deal more good from the accident than it will occasion me of trouble in repairing the damage."

Lawrence went on to say that the principle which he referred to was this: That force was an agency that existed always in definite and measurable quantities, such that, though it might be transferred from one place of deposit to another, and so be accumulated or dispersed, it could not in any way be increased or diminished.

"Yes," said John, "it can be increased; for when your grindstone was spinning round very fast, it exerted a great deal more force than Rick did by the power of his foot."

"It exerted more force in *any one instant*," said Lawrence, "than Rick could exert in *that instant;* but the whole amount of all the impulses that Rick gave to it was equal to all that the grindstone could exert; that is, there was in the stone an accumulation of a great many small forces, and not any increase of the whole amount.

"It was like filling a pail with water by pouring in a great many mugsful from a spring," continued Lawrence. "It is true, you may increase the quantity that is *in the pail*, and in that sense we may say there is an increase; but there is no actual increase on the whole, for the amount that is in the pail, when it is full, is only made up of the separate amounts of all the dipperfuls. There can not be, absolutely, in the whole amount, any increase or diminution."

"There might be a diminution," said John, "for some of the water might be spilled."

"True," replied Lawrence, "a part might be spilled, and a part might dry up; but none of it would cease to exist on that account. Wherever it went when it was spilled, or wherever the vapor went of that which was turned into vapor, there it would be. There might be a diminution of the quantity in the pail, but there could be no diminution of the actual amount of water employed in the experiment. Precisely the same amount, neither any more nor any less, would exist *somewhere* at the end of the experiment that existed at the beginning.

"And it is just so in respect to force," continued Lawrence. "Precisely the same quantity that we have at the commencement of any process, or at the entrance, so to speak, of any combination of machinery, exists *somewhere* at the end of the process; or, in the case of machinery, must be stored in it, or must issue from it in some way. There can not possibly be any real gain or loss of force any more than there can be of water. A great many small or gentle forces may be combined to make a great one, and, on the other hand, a great one may be subdivided into many small ones, but there can not, in either case, be any absolute increase or diminution of the amount.

"Take, for example, the case of wind blowing the trees, as shown in the engraving. Nothing can seem, at first view, more vague and indefinite than such a force as this, and yet nothing can be more strictly defined and determinate in its nature than the action of the breeze in such a case really is. For every leaf, and for the area of every branch and stem, there is a certain stream of particles of air, each moving with a certain definite velocity, and all consequently striking against the leaf or the stem with a certain force; so that, if the quantity of air in one of the streams, and the rate of its motion, were known, the precise amount of the force which it would exert would be determined. Each particle strikes with a definite force, depending upon its weight and its rate of motion, and this amount of force

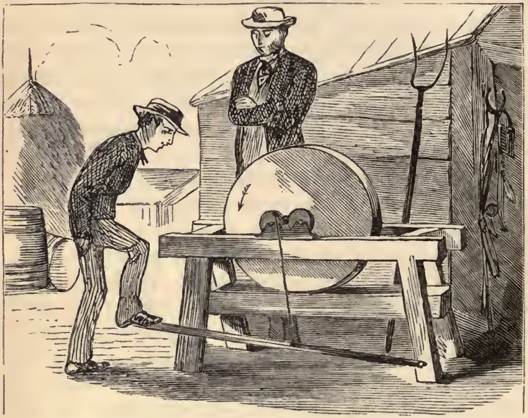
FORCE OF THE WIND.

can not be made either less or more while those conditions remain unchanged.

"Thus every force which we see acting in nature around us exists in precise and definite quantities, which can indeed be made to pass from one body into another, and in that way can be accumulated, and can be made to change, too, from one form into another, as will be more fully explained hereafter; but the amount can never be increased in any other way than by uniting a great many small forces into a larger one, or diminished in any other way than by dividing a large one into many small ones, in neither of which cases is there any absolute increasing or diminishing of the absolute amount.

"It results from this, that whenever we see any force, however great, in action, as, for example, in the case of a windmill turning with great speed, or a steam-engine driving a ship through the water with great power, and we wish to investigate it philosophically, the first question to be asked is, Where does the force come from? and in the same manner, when we see a force disappearing, as, for instance, when an express train that has been moving with great impetuosity is gradually brought to a stand, or a bullet in rapid flight through the air is stopped by a wall, we have to inquire, Where has the force gone to? The idea that either, in the one case, it has been created or called into existence by any kind of contrivance or mechanism, or, in the other, that any portion of it, however small, can have come to an end, or ceased to exist, is wholly inadmissible; and this principle of the absolute continuity and persistence of all the force which is in action in the visible universe around us lies at the foundation of all real knowledge on the subject."

We have an excellent illustration of this principle, in one of its forms, in the rotation of the grindstone, as impelled by the efforts of Rick, which produced in the end such a violent result. The great force of rotation which the stone acquired consisted only of an accumulation of a great many small forces imparted to it by the pressure of Rick's foot upon the pedal, as may be seen in the action of a common grindstone in any farmer's yard.



CRANK MOTION.

The grindstone, turning in the direction denoted by the arrow, whenever, at each rotation, it comes into the position represented in the engraving, the boy, bearing with his whole weight upon the end of the treadle, transfers all the force represented by the descent of that weight to the crank, and so to the stone. Of course, when the crank comes down to the lowest point, and then turns to go up on the other farther side, the boy raises his foot, and then, as soon as it passes over the highest point, and turns to come down on the hither side, he bears on again with all his force, and so adds another impulse to the motion of the stone; that is, he sends in, as it were, an additional force to be added to what he had imparted before. Thus he goes on sending in an addition to the force previously communicated to the stone, at every rotation of it, until the quantity accumulated becomes very large.

The reader who likes to have precise ideas on any subject of this kind will perhaps be interested in seeing how exact calculations are made in such cases as this, and how quantities of force can be measured and expressed numerically. Let us suppose, then, that Rick weighed ninety pounds, and that at the right moment of each revolution he bore with his whole weight on the pedal. Let us also suppose that the end of the treadle-bar on which his foot rested descended at the rate of six inches in a second. Then the force that he imparted would be that of ninety pounds moving at the rate of six inches a second. Now let us suppose that the stone weighed six times as much as Rick's body; then the force which Rick imparted to it would be a motion one sixth as great—that is, the motion of one inch a second.

This means, of course, an *average* motion of all the parts of the stone. The parts near the circumference would evidently move much more rapidly than the parts near the centre. Then, again, some portion of the force which Rick's weight would exert would be expended in overcoming the friction, and there would be many other considerations connected with the manner in which the pitman—that is, the connecting rod between the crank and the middle of the treadle-bar*—acts in the different parts of its course; but the general principle is simple and plain, as Lawrence

---

* A connecting bar of this kind in machinery, which acts in communicating force by a reciprocating motion up and down, is called a *pitman*, from the analogy of its action to that which the man who stands in the

presented it to the boys, namely, that the whole of the very considerable force with which the stone revolved at last was made up by the accumulation of comparatively small forces which Rick impressed upon it through the treadle as the crank went round; and that the whole amount of the greater force, together with the small portion which had been deflected through friction, was neither more nor less than exactly equal to the *sum* of all the smaller ones.

A heavy wheel like this grindstone, moving with a force made up of the sum of a great many smaller ones, is not only an accumulator of force, but it acts also as an *equalizer* of its flow. The force imparted to it is intermittent; that is, it consists of a succession of impulses; but the force with which the stone revolves is steady and uniform. This is of great importance in the case of the grindstone, because it is necessary, in grinding, that the tool should be held upon the stone with a uniform and steady pressure; and if the stone were not heavy—that is, if it did not contain a large quantity of matter, to continue steadily in motion when motion was once imparted to it—it would be stopped by the friction of the tool when the crank had passed the lowest point at each revolution, and was ascending on the farther side, during which part of its revolution no additional force could be imparted to it.

All machinery which is moved by a succession of impulses such as those given by means of a crank must have some heavy wheel to receive and store, and thus equalize the force. When the machinery itself consists of heavy wheels, they serve this purpose themselves; but when the machinery is light, as in the case of a sewing-machine, a heavy wheel must be expressly provided to accomplish this end. Such a wheel is called a *fly-wheel*, and is usually

pit, in sawing, exerts in pushing up and pulling down the saw, by means of the handles on the lower end of it.

made of iron, with the greatest portion of the weight in the rim, where the motion is swiftest, and where, of course, the greatest quantity of force can be stored. Such a wheel may be seen connected with the treadle beneath the table in any sewing-machine. In some cases these fly-wheels are of immense size, and are generally used as above explained in receiving and storing large quantities of force received in intermitted impulses—which is always the character of the force transmitted by a crank—and delivering it afterward to other parts of the machinery in a continued and equable flow.

The principle which was thus illustrated by the case of the grindstone, that whenever we see force of any kind or in any quantity in action, we may be sure that it proceeds from some other force previously existing in the same or in some other form, and precisely equal to it in amount, and that when it ceases to act it is not annihilated—that is, it does not cease to exist, but passes off into some other body in the same or in some other form, but without at all changing its amount, is universally true. The case of the grindstone does not, indeed, prove this principle. It is only one illustration of it. The case of the grindstone, moreover, only shows the operation of it in respect to the equality between impulses of force communicated by Rick's foot, and the revolving force of the stone made up by the accumulation of these impulses. Lawrence did not show where and in what form the force existed before it appeared in the boy's foot, or where it went in its disappearing, as the grindstone gradually came to a state of rest. These points he reserved to be considered and explained another time. The principle itself has, however, been fully proved to be universally true, so fully that there is no longer any doubt of it in the minds of any scientific or even well-informed man.

It would have been well for mankind if this great truth could have been earlier and more generally understood, for it would have saved many, many years of valuable time spent, and vast sums of money that have been wasted, in attempting to contrive means for the *production of force*, under the name of machines of perpetual motion. The phrase perpetual motion is an unfortunate one, in a philosophical point of view, inasmuch as we have perpetual motion already all around us, every where, instead of its being any thing new yet to be discovered. The particles of all bodies that we know are in a state of incessant movement. The earth itself is in rapid rotation around the sun, and the most solid rocks are constantly undergoing internal changes produced by expansions, and contractions, and other movements of the particles among themselves. Thus, instead of there being any difficulty in producing perpetual motion, it is impossible to escape from it. We can not by any conceivable means produce in any substance a condition of absolute rest.

The real object of the so-called perpetual-motion machines is the *creation of force*, or the expanding of a single small force into a great one by means of some ingenious combination of levers and wheels, or other machinery—effects which, by the very constitution of nature, can not possibly be produced. In all cases where a new machine is proposed for doing work, the first question to be asked in respect to it is, *From what source is the force derived* by which the machinery is driven? If any adequate source of force is pointed out, the machine *may be* a success. This source of force may be in the movement of the wind, the falling or running of water, the rising or falling of the tide, the combustion of wood or coal, as in a steam-engine, or that of zinc, as in an electro-magnetic engine. There must be a source of force somewhere, external, in its nature, to the machine which it sets in motion; for no machinery can by any possibility create or produce its own force, or increase in the least degree the amount which is furnished by the source, whatever it is, from which it draws its supply.

Let every reader of this book, therefore, understand and fix indelibly this fundamental principle, namely,

All force, as it exists in nature or in human contrivances, exists in fixed and definite quantities, which can not be increased in any other way than by accumulating many small forces to form a great one, or diminished in any other way than by being divided and dispersed.

CHAPTER III.

MECHANICAL FORCE.

In the case described in the last chapter, the function of the grindstone, in respect to its action as a fly-wheel, was this, namely, to receive the force in the form of a succession of impulses imparted by the weight of Rick at each revolution of the crank, and then to deliver it, at the surface of the stone, in an equable and continuous flow. In some cases, however, the action of a fly-wheel is the reverse of this. It receives the motion in a continuous flow from the machinery by which it is driven, and delivers in a succession of impulses, when such impulses—that is to say, intermittent exertions of force—are required by the nature of the work to be done.

IRON SHEARS.

Such intermittent action, for example, is required in the case of such an engine, as is shown in the accompanying engraving, for cutting off heavy iron bars into portions of a given length.

It seems wonderful that bars of such thickness can be cut off in this manner at a single stroke by a pair of shears. But there is no difficulty in doing it, and that, too, with great rapidity, provided that a sufficient force to overcome the cohesive strength of such a mass of iron is accumulated in the immense fly-wheel, which always forms a part of such machinery, and is brought to the work by a band or some other connection, and that the jaws of the shears are made massive and solid enough to hold the force and deliver it all at the precise point or line in the iron bar where it is required. The iron is cut off in such a case as if the bar was one of wax. The portions are made equal by means of the gauge seen toward the right, against which the workman, after each portion is cut off, pushes the bar, and thus measures another portion to be cut off at the next descent of the cutter. The portions thus cut—forming short bars—fall in a heap upon the floor below.

In this case it is evident that the steady and equable force involved in the motion of the ponderous fly-wheel, or in that of other portions of the machinery not seen in the engraving, is delivered, not equally and steadily in doing its work, but in a series of prodigious though momentary impulses, each one taking effect during the instant that the jaw of the shears is coming down to cut off the bar. During the time while the jaw is rising again, and the workman is pushing the bar forward into the right position for a new cut, there is, of course, an intermission in the expenditure of force, for it is plain that comparatively very little force is required for raising the jaw to its former position in order to bring it into readiness for a second stroke.

Thus it is plain that in such a case as this the force that is stored in the fly-wheel of the machinery is delivered, not in a continuous flow, but in a succession of very powerful impulses.

A curious example of the different modes of the transmission of force is given in the accompanying engraving, from a drawing made by a French traveler of a primitive species of lathe which he observed in use among the natives of Algeria, in Africa.

The cord, it will be observed, on which the man bears his foot, is passed once around the spindle which forms the axis on which the work is fixed, and the farther end of it is attached to the end of an elastic wooden spring. By this arrangement, of course, in bearing upon the cord with his foot, the workman causes the axis, with the work upon it, to revolve, and the top of the elastic rod to bend toward him. Thus a portion of the force which he impresses upon the cord is conveyed to the axis and to the work, and another portion is expended in bending the spring, thus storing itself, as it were, in the elasticity of the wood. When the workman raises his foot, this stored force comes into action to turn the axis and the work upon it back to its former position. Thus the man turns the axis and the work back and forth by an alternating motion, turning it forward by the *direct* action of his foot, and back again by the force imparted to the wooden spring, and stored in it till it comes into action again when the pressure of the foot is relieved.

In precisely what condition a force can be stored in this manner in the elasticity of a substance, so to speak, we shall see hereafter, so far, at least, as in the present state of our knowledge on the subject it can be explained.

Although this engraving answers very well as an illustration of the points above referred to, it still represents a very awkward arrangement for any practical purposes of turning except the shaping of pottery, as there is no convenient mode shown for supporting the tool, though the long bar seen between the workman and the work would serve this purpose for a certain part of the operation. The

A PRIMITIVE LATHE.

tool, in almost all cases in turning, requires a fixed and very firm support.

Lathes for practical purposes are, however, not unfrequently made on a principle substantially the same as is illustrated in this example, by farmers' boys and other persons who do not wish to incur much expense in their work. The spring, however, in these cases, instead of being set up perpendicularly in the floor, is placed horizontally above, over the bench, the fixed end of it being fastened to the beams or rafters, and the free end extending over the work. The work is held between two pivots set in blocks, which blocks are set firmly in the bench. The cord from the free end of the spring is brought down, and, after being carried once round a part of the wood to be turned—in a little groove made for it—passes down through an opening in the bench made for the purpose to a treadle, constructed somewhat like the treadle of the grindstone, below, near the floor. Of course, the workman can cause the work to revolve three or four times in the direction required for his tool by bearing down upon the treadle, and then, on raising his foot, the spring draws the treadle up again, carrying the work round by a backward motion into its original position. There is a bar of hard wood, which passes across from one of the blocks to the other, to serve as a rest for the tool in turning. Such a lathe as this is called a *spring lathe.*

This kind of lathe, though comparatively easy to make, is not very convenient, or, rather, efficient for work; for, as the wood to be turned does not revolve continuously in the same direction, but turns and returns by a series of alternating movements, the tool must only be held up to the work while it is moving in the right direction. Of course, it is only half of the time that the tool is producing any useful effect. Then, moreover, as there is no fly-wheel to steady and equalize the motion, the action is not so satisfactory in any respect.

For such a lathe as this, some building which can be used as a shop is required, and a considerable degree of strength, and some experience and skill in doing such work, is necessary for the construction of it. There is another kind, however, in which the force is transmitted in a somewhat analogous manner, that any ingenious boy can make, and which can be used on any table by the fireside.

THE BOW-LATHE.

It is called the *bow-lathe*, because it is worked by means of a bow held in one hand by the workman, while he manages the tool with the other. It consists, in its simplest form, of a board of any convenient size—as, for example, a foot long and six or eight inches wide—with two standards near the two ends, as shown in the engraving. There is a bar extending horizontally from one of these standards to the other, at the proper height, for a " rest" to support the tool. Near the top of each standard is inserted a screw. The inner ends of both of these screws are carefully formed into smooth tapering points, to enter into the ends of the piece of wood to be turned. Common "wood screws,"* as they are called, will answer this purpose very well, but they should be of good size, and the ends should be prepared by filing off the threads for half an inch, and carefully forming a conical point at the end of each. These ends should be ground smooth, and then polished upon a whetstone, so as to prevent their wearing the wood. The tips should also be oiled a little when in use. The screw at one end, besides passing through the top of the stand, should also have a small block like a nut on the outside, as shown in the engraving, by means of which it can be held tight in its place while the work is going on.

Any boy with ingenuity and skill enough to make a bow and arrow can make such a bow as is required for a lathe of this kind by taking the one represented in the engraving as his guide as to the form. The string should be a very close and compact one; cat-gut is best.

The wood to be turned must be made of the right length, and then shaped roughly to the size and form required. Small holes must be made in each end to receive the pivots, and a quarter of a drop of oil put in each. The cord of the bow is to be wound once round the wood, and then, one end being fitted to the left-hand pivot, the right-hand screw is to be turned forward till the point enters the hole in the other end, so as to hold the wood in its place, and the binding nut at the end is to be tightened. The boy then, holding the bow in his left hand, and the tool—which must be at first of the *gouge* form—in his right, begins his work.

The first thing to be done with the tool is to form a groove near the left-hand end of the piece of wood for the cord or bow-string to run in. In the engraving the bow-

---

* So called because, though made of iron, they are intended to be *used* in wood.

string is represented as encircling the wood in the groove; but the place which it must occupy while the workman is cutting the groove—which must be done by holding the tool in the left hand—is a little to the right of it. The drawing is made in this way the better to show the ultimate form and position of the groove. Of course, when the groove is finished, the bow-string must be run along to the left, into it, and then the work, with the gouge to the right, can go on regularly.

If the young workman finds that he can not manage the tool with the left hand very well in making the groove, he can, if he chooses, turn the piece of wood end for end between the pivots, and so form the groove in what will be the right-hand end of it, and then reverse it again when the groove is made.

However this may be, any boy, however ingenious, may depend upon finding this work for a time full of vexation and discouragement; for the great difficulty in the case of such a lathe as this is, not to *make* it, but to acquire the skill to use it. It is difficult, in the first place, to attach the bow to the piece of wood to be turned, with the cord wound once around it in such a manner as to bring the bow on the upper side of it; though, after one learns to do this, nothing is more easy. Then it is difficult for a young workman to acquire the knack of moving the bow with one hand and holding the tool with the other, and of pressing the edge of the tool up to the work only while pulling the bow toward him, for it is only then that the wood is revolving in the right direction. Then, after learning to work successfully with a gouge-shaped tool, it is very difficult to learn the art of smoothing the work with a chisel, for it is almost impossible for a beginner to prevent the corners of the chisel from catching in the wood.

Any intelligent boy, however, who has ingenuity, patience, and perseverance enough to surmount all these difficulties, will be able to amuse himself a great deal with such a contrivance as this, and when he learns to manage it right, can turn small ninepins, and tops, and checkermen, and tool-handles, and other such things with it, and in so doing will learn practically a great deal about force, and the art of dealing with it, and the action of it upon different kinds of materials, and will acquire much other knowledge which will be of great use to him in helping him to understand machinery, and lead him to take an interest in it as long as he lives.

In fact, lathes constructed on precisely this principle, but made neatly of iron and brass, are in constant use by mechanics for light turning, as any one can see by inquiring at any jeweler's or watchmaker's, and watching one while it is in operation.

The watchmakers turn arbors, and wheels, and screws, and other small work, sometimes of brass, and sometimes of softened steel, in such lathes. They secure the lathe itself firmly, while they are using it, by holding it in a vice which is secured to their bench. A wooden lathe of this kind, to be used upon a table, may either be made upon a plank base heavy enough to keep it steady, or, if the base-board is thin, it may be held to the table by clamps made of blocks of wood of the right size, with square notches cut in them, tightened by wedges crowded in either between the upper side of the notch in the clamp and the base-board above, or between the under side and the lower edge of the table below.

But to return to our story. Lawrence explained to John and to Rick some of the principles here referred to in respect to the management of that form of force which consists in mechanical motion, in the course of conversation with them at the grindstone and at the lathe. After having remedied the damage done to the treadle of the grindstone, he went to the lathe, asking Rick, by the way, what was the best kind of wood for him to take to make the bat of.

"The very hardest and toughest kind of wood that you can get," said Rick. "You see the balls are very hard, and we strike with all our might, and the bats, no matter how hard the wood is, soon get broken or battered to pieces."

"Yes," said Lawrence. "You draw the bat back as far as you can, and then you concentrate in it all the force you can impart to it from your arms through the whole length of the swing of them, and deliver the whole in a single instant into the ball."

"And send it spinning," said Rick.

Lawrence asked how *ash* would do; but Rick said that ash would not do at all. "It is tough and springy, and good enough for some things," he added, "but it soon splits into shivers if we use it for a bat."

Lawrence finally made choice of a piece of seasoned maple, and fixed it in the lathe. He asked Rick various questions about the length and the other dimensions best for a bat, and followed his directions exactly in marking out the work. Then, when he was ready to begin, he took a gouge, and asked Rick if he would work the treadle for him while he turned.

"Oh yes," said Rick; "I can do that well enough."

Rick began, and, to show how well he could do it, he was soon driving the machinery so furiously that Lawrence was obliged to check him, telling him that a moderate and steady motion was what was required.

Rick watched the effect of the gouge upon the rapidly revolving wood, and soon began to be greatly interested in the operation. At last Lawrence put the gouge into his hands, and asked him to see if he could not work the treadle and manage the cutting too. Rick seemed at first to hesitate, but he soon became willing to make the attempt, Lawrence standing by and watching the operation. John was then in another part of the shop.

RICK AT THE LATHE.

John had listened to Lawrence's explanations, and to his account of the bow-lathe, with much interest, and, although he had the use of Lawrence's lathe, which was, of course, much more convenient for actual use, he determined that he would make a bow-lathe for himself some time, "just for fun," as he said. Lawrence proposed to Rick that *he* should make one too, promising to help him in doing it. But Rick replied somewhat churlishly that *he* did not want such a thing. He did not think that it would do *him* any good.

However, when he came to the trial of the gouge in Lawrence's lathe, and found how easily and how well he succeeded in bringing the rough piece of wood into an approximation to its true form for a bat, he became for a few minutes somewhat interested in the operation, though it is probable that this interest depended altogether, or almost altogether, upon the fact that it was a *bat* that he was making, and extended very little to the scientific considerations in respect to the nature of force which were involved in the process of turning.

After the bat had been brought substantially into its proper form by the gouge, Lawrence finished it with the chisel, and smoothed and polished it with sand-paper, while Rick worked the treadle, driving the machinery—as it was proper to do in the process of polishing—at great speed. When it was finished, Lawrence took it out of the lathe and handed it to Rick.

"Now let us go out and try it, and, if you like it, you can have it. Or can you tell by handling it how it will work?"

"I can tell pretty well by the feeling of it," said Rick, taking hold of it with his two hands, and holding it out as if about to strike a ball with it.

"Yes," said he, "that will do pretty well. But I have got a ball in my pocket, and we will go out and try it. But do you say I may have it for my own?"

"Yes," replied Lawrence. "Only you must come back in a few days after you have tried it on the play-ground, and tell me how it works."

So they went out upon the grass-ground behind the shop to try the bat. John remained in the doorway looking on. Rick took a ball out of his pocket, and tossing it a foot or two in the air, and bringing the bat into position in a moment so as to intercept it as it fell, he struck it fair and square, with tremendous force, at precisely the right instant of its descent. The ball soared to a great height. Rick followed it with his eyes, and then began to walk along rapidly in the direction it was going. He caught it as it came down, put it in his pocket, and walked off in the direction toward home without looking around at all to Lawrence and John, and without any word, either of thanks or of parting, at leaving them.

Lawrence turned toward the door where John was standing, and advanced with a very curiously expressive smile upon his countenance. John was writhing to and fro in convulsions of laughter, now stooping down with his hands upon his knees, and now holding his sides in desperate efforts to restrain himself within such bounds that Rick should not hear him.

"A perfect failure!" he said, as soon as he recovered sufficient composure to speak articulately. "I told you you could not interest him in any thing beyond ball-playing."

"Perfect success!" rejoined Lawrence. "I am entirely satisfied with the result of my first experiment."

And so they went back into the shop.

CHAPTER IV.

TRANSFER OF FORCE BY PULLEYS AND BANDS.

THE word force, in common parlance, is used in a great many different senses, some of which are quite vague and indeterminate. As used by Lawrence in his conversation about wheels and machinery with John and Rick, as narrated in the last chapter, it relates solely to what is sometimes designated as *mechanical force*—that is, the visible motion of masses of matter. There are various other forms of force, which consist, as will hereafter be shown, of changes taking place, or of effects produced, in the *internal constitution* of substances. These will be considered hereafter. We are now dealing only with *mechanical force*, or energy, which is compounded in respect to its quantity, and with reference to a certain important class of effects produced by it of the quantity of matter that is in motion, and the velocity with which it moves.

But this kind of mechanical force, it is evident, may exist in a great variety of forms, or rather, perhaps, *conditions.* It may be rectilinear and continuous, as in a block sliding upon ice; it may be *rectilinear* and *reciprocating*, as, for instance, in the case of the piston of a steam-engine, which moves to and fro, or up and down, in successive alternations; it may be *uniformly accelerated*, as when a grindstone is made to go faster and faster by uniform additions to its velocity every instant, or when a weight let fall from a height descends with steadily increasing velocity to the ground; and it may be *intermittent*—that is, it may advance by a series of distinct impulses, with intervals of rest between them. And so it may be *rotary continuous* or *rotary intermittent.* In a word, the number and variety of kinds of motion which may be required in working of machinery is without end; while all of them must be derived from one common source—whatever that source may be—whether the up and down motion of the piston in the steam-engine, or the slow revolving of the great water-wheel in the mill.

Now nothing is more common than the number and variety of the contrivances by which mechanical force is transmitted, and modified in transmission, in the construction of machinery. Of course the number of *possible* combinations of this kind is, in theory, unlimited, and the number of those that are actually in constant use is exceedingly great. We have before us a work describing and illustrating more than five hundred of such elementary movements.* Some of these, especially such as illustrate the most important and fundamental principles, will be described in this chapter. If the reader will study them attentively, they will not only afford him a clearer general insight into the nature and workings of mechanical force, but will aid him much in understanding the construction of such machinery as he may, from time to time, have opportunity to examine, and will greatly increase his interest in it.

One mode by which mechanical force is transferred from one revolving shaft to another is by a band. These bands are made sometimes of *cords* running in grooves, and sometimes of broad *belts* of leather, or some similar substance, running upon the wide pulleys, being prevented from slipping upon them by friction. You will often see in large manufacturing establishments a long shaft placed near the

---

* Brown's Five Hundred and Seven Mechanical Movements. *Artisan* Office, New York.

ceiling, and extending the whole length of the apartment, with pulleys here and there along the whole extent of it, and bands bringing down the force, so to speak, to a great variety of different machines on the tables or benches of the workmen below.


Fig. 1. OPEN BELT.

If, in such a case, the motion is communicated by what is called an *open* belt or band—that is, one not crossed, as in Figure 1—the motion of the lower pulley, through the force transmitted from the upper one, and consequently that of the shaft which the lower one carries, will be in the same direction as that of the upper one.

On the other hand, if the belt be crossed, the direction of the motion will be reversed.


Fig. 2. CROSSED BELT.

Very often, of course, the workman at the shaft below will wish to stop his own particular machine without interrupting the movement of the shaft above, by which all the other machines are carried as well as his own. A contrivance is accordingly adopted by which the connection of his machine with the shaft above may be suspended and restored at pleasure, which contrivance consists of what is called the *fast and loose* pulley. This is illustrated in the engraving, Figure 3. The pulley on the upper shaft, it will be observed, is single, while the corresponding one on the lower shaft is double. The upper pulley is fixed firmly to its shaft, and must revolve with it, but the *left* half of the lower one is loose, while the right half is fast. Thus, by slipping the band from the loose pulley to the fast one, or from the fast one to the loose one below, the machine driven by the lower one may be stopped or set in motion at pleasure by the workman,

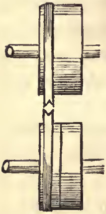


Fig. 3. FAST AND LOOSE PULLEY.

without interfering with the continued motion of the great shaft above. The pulley on the upper shaft is made broad enough to take the band from either of the pulleys below.

In Figure 3, the lower shaft is placed for convenience quite near the upper one, but in practice such connections are made by belts extending a considerable distance from

BURNISHING MARBLE PAPER.

the shaft above to the working machinery below, as is indicated by the break in the belt shown in the figure.

A good example of this bringing down of the force by a long band from a shaft above is shown in the engraving of the process of burnishing marble papers as performed in Harper's establishment.

The long band on the left is the medium by which force is communicated from the shaft above to the one below, near the work, the pulley below being double, one part being fast and the other part loose, so that the operator can put in motion or stop the burnisher at pleasure.

The burnisher is formed by a highly-polished surface at the lower end of the long bar hinged at the ceiling, and worked to and fro over the surface of the sheet of paper upon the table by means of the transverse bar seen near the middle of the picture, which is made alternately to push and to pull the burnisher by means of the crank indistinctly seen to the right of the small fly-wheel on the lower shaft. Thus this engraving, besides illustrating the form and functions of a band for conveying force, serves also as an example of the manner in which a continuous rotary motion is converted into a reciprocating rectilinear one.

In the above-described cases, the two shafts—one of them furnishing, and the other receiving the force—are parallel to each other. The wheel, however, which is to receive and be driven by the force, may have its axis at right angles, or at any other angle to the shaft from which its force is to be derived. All that is necessary in such a case as this is so to arrange the pulleys that the band can take the direction indicated in Figure 4.


Fig. 4.
AXIS AT RIGHT ANGLES.

The nature of the effect produced by the transfer of force in these ways from one pulley to another upon different shafts depends greatly on the comparative dimensions—in circumference—of the two pulleys.


Fig. 5.
PULLEYS OF DIFFERENT SIZES.

In Figure 5, for example, the upper pulley, we will suppose, is of one half the diameter, and, of course, of one half the circumference of the lower one. Let us suppose that the circumference of the upper one is two feet, and that of the lower four feet. Then the upper shaft, in one revolution, will only carry over two feet in length of the band. But two feet in length of the band will only carry the lower pulley through one half a revolution, so that it will take two revolutions of the upper shaft to produce one of the lower.

On the same principle, if the upper pulley is larger than the lower one, the revolution of the lower will be proportionally greater in speed. If a wheel thirty feet in circumference upon one shaft drives one of three inches circumference on another, the latter will make one hundred and twenty revolutions for every one of the former.

Or the process of producing the acceleration may be divided, as it were, by introducing an intermediate shaft. For example, the upper pulley may be ten times greater in circumference than the second one, which will cause the second one to revolve ten times as fast as the first; and then there may be a pulley on this second shaft, with another band connecting it with the third shaft, the pulleys being in the same proportion—that is, ten to one. Thus, the third shaft revolving ten times as fast as the second, and the second ten times as fast as the first, there will be a hundred revolutions of the third to every single revolution of the first.

It is very important to remember that there is no loss or gain whatever of *force* in these transmissions; for what is gained in speed is lost in power, and what is gained in power is lost in speed. In some cases, as, for instance, in *polishing*, great speed is required, with but little power. In others, as in the case of the shears for cutting iron bars, as shown in a former chapter, a slow motion, combined *with great power*, is the object to be attained; and thus, in the construction of machinery, the relative sizes of the driving and driven wheels are determined by the comparative degrees of speed and power required for the purposes intended.

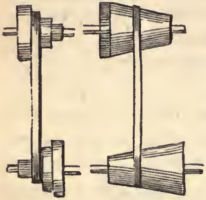


Fig. 6.
MEANS OF VARYING SPEED AND POWER.

Sometimes there is a set of pulleys of different sizes on the upper shaft, with a corresponding set in the reversed order on the lower one, so that the band can be shifted to any pair at the pleasure of the workman, according to the nature of the work that he has in hand. For instance, in the case of a lathe, if he has iron to turn, he requires, while cutting away the iron, little speed and great power, and for this purpose he carries the band over the pair of pulleys on the right, as shown in the left-hand part of the engraving, Figure 6. But when he comes to the work of polishing the surface of the iron, after it is finished as to its form, he requires great speed and little power, and then he shifts the band toward the pulleys on the left. Sometimes these systems of wheels are blended into cones, as shown in the right-hand part of the engraving, the relative speed of the two shafts depending upon the part of the conical surfaces which the band passes over for the time being.

In the large manufacturing establishments of modern times, the quantity of force that is transmitted in this way by bands, and the magnitude of the pulleys and bands by which it is transmitted, are often enormous. There is an account in the newspapers, at the time of the writing of this chapter, of a pulley put up in a mill in Fall River, Massachusetts, twenty-seven feet in diameter, and weighing over *sixty tons*, and also of a belt of leather used in a certain mowing-machine factory of such dimensions as to consume *one hundred and fifty hides* in the manufacture of it, and weighing nearly a ton. The force conveyed by such machinery as this is sufficient, when divided and distributed among the spinning-machines of the mill, to drive from fifty thousand to one hundred thousand spindles.

CHAPTER V.

TRANSFER OF FORCE BY GEARING.

But, besides the use of bands, there is another mode of connecting shafts so as to communicate force from one to another, and that is by what is called *gearing*—that is, by means of notched wheels, the teeth of which "engage" with each other, as shown in Fig. 7. In this case, as in that of the belt or band, the relative speed of the two shafts will depend upon the relative circumference of the two wheels, as measured by the number of teeth in each. For example, if in the figure the left-hand wheel is the driving one, and has thirty teeth, while the one on the right, which is driven, has forty, it is plain that when the former has made one revolution, its thirty teeth will only have engaged with and carried forward thirty of the teeth of the large wheel —that is, will have carried it only through three quarters of a revolution; or, in other words, that it will take four revolutions of the one to produce three revolutions of the other; but the power with which the shaft of the larger wheel revolves will be proportionally increased. Thus the proportion of speed to power, in the transmission of the force, can, in this case, as well as in that of force transmitted by a band, be regulated at pleasure by the comparative sizes of the wheels.

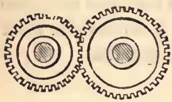


Fig. 7.
GEARING.

But, what is still more curious, not only can the whole revolution of the shaft that is driven be accelerated or retarded by making the wheel by which the force is received larger or smaller in circumference than the one from which it receives it, but its speed may be varied at *different portions of the same revolution* by varying the curvature of different portions of it. Of course the curvature of the driving-wheel must be varied to correspond, so that the distance from the centre of one shaft to that of the other through the two teeth which are engaged at the several successive moments of rotation shall be "constant"—that is, always the same.

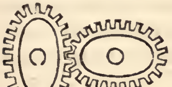


Fig. 8.
VARIABLE SPEED.

In Fig. 8, for example, we have two oval-shaped wheels geared together. In the position in which they are shown in the engraving, that part of the right-hand wheel where the curvature is *great*—as if it were a portion of a small wheel—is engaged with a portion of the left-hand wheel where the curvature is small, like that of a portion of a large wheel. In this part of the rotation, therefore, if the left-hand wheel is the *driving*-wheel, the motion that it would communicate would be quick; but, as the movement goes on, the upper part of the right-hand wheel, where the curvature is small—making it like a portion of a large wheel—is brought into connection with a portion of the driving-wheel where the curvature is great. The motion of the right wheel will consequently here be quickened. By such an arrangement as this, therefore, the comparative speed of the two wheels will be changed four times in each revolution.

When the forms of the wheels are not so adjusted that the distance from centre to centre through the teeth engaged is always the same, then one centre or the other must be movable, to allow this distance to change; and the kind of motion thus imparted may be infinitely varied, according to the forms of the wheels, and the manner in which they bear upon each other. Thus the most complicated motions, or, rather, motions of any character that may be required, can be derived from perfectly uniform rotation, as, for example, in Fig. 9, where the lower wheel acts on the irregular shaped one above. Here the distance from centre to centre through the teeth that are engaged is not constant, and, of course, the centre of the upper one must rise and fall, carrying the bar with it at every oscillation. By this means quite a complicated oscillatory motion is given to the bar.

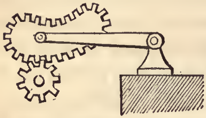


Fig. 9.
COMPLICATED MOVEMENT.

Very complicated motion, both of revolution and oscillation, is required for many purposes in machines. For instance, in some forms of power printing-presses the movement must pause a moment in a certain part of its course to allow time for the attendant to place the sheet of paper to be printed properly on the frame, and also again in another part to continue the pressure of the types upon the paper long enough for the proper absorption of the ink into its texture. And so in the manufacture of pins. A central horizontal wheel is provided, with a number of bars like spokes, each of which, as the wheel revolves, receives and carries round a piece of wire of the proper length to form the pin. There are small subordinate machines placed around the circumference of the central wheel, each of which performs a specific operation, and, of course, the central wheel must pause long enough at regular intervals to allow these subsidiary machines to perform their appropriate work, as the pins, in the process of formation, come successively to it. For instance, the wheel must pause an instant at the beginning of its course, where the wire is received, to give the machine intended for that purpose time to measure and cut off the proper length of wire, and then again at the end of the first quarter of the revolution, to have the point formed and sharpened, and at the next to have a head put on, and so on until at the end the pin is dropped in a finished state into its receptacle. The successive motions and pauses thus required must be given by means of proper forms in the wheels, by which uniform and continuous rotary force is modified in transmission.

And so in winding thread upon a spool. The spool must revolve, and at the same time move laterally, by just the diameter of a single thread at each revolution, in order to receive one layer of thread smoothly and regularly upon it; and then, when the winding has proceeded once across to the farther end of the spool—the left-hand end, for example—it must reverse its lateral motion, while the rotary motion is continued without interruption, so as to carry the winding in a second layer of thread back to the right-hand end. And all this must be done by modifying the action of force absolutely continuous in its source, but modified solely by the *forms* through which it is transmitted.

Sometimes, however, the reverse of this process is necessary—that is, the source from which the moving power is derived is not uniform, and has to be made uniform in its action by the mechanism. This is the case in the watch, and in some clocks, the works of which are carried by the uncoiling of a spring. In this case, as the process of uncoiling goes on, the force becomes weaker and weaker by the diminishing elasticity of the spring; and the diminution must be compensated for by an increase in the circumference of the wheel on which the force takes effect, which result is attained by a contrivance called the barrel and fusee, shown in Fig. 10.

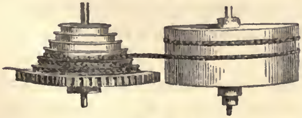


Fig. 10.
BARREL AND FUSEE.

The coiled spring is contained in the barrel, and the chain which conveys the force turns the fusee, the circumference of which is formed *in a spiral*, so that the portion of the circumference which is acted upon continually enlarges itself as the spring uncoils.

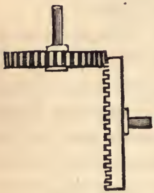


Fig. 11.
CROWN WHEEL.

In all the preceding cases the axis of the two wheels transmitting and receiving force are parallel to each other. When they are at right angles to each other, the teeth of one of them are sometimes formed upon a kind of rim or margin, at right angles to the plane of the wheel, making a *crown*, as it were, from which circumstance such a wheel is called a *crown wheel.*

Another mode by which motion may be transmitted from one axis to another at right angles to it, or, indeed, at any other angle, is by beveling the margins of the wheels in the part where the teeth are to be cut, so that they may engage each other at the desired angle, whatever it may be.

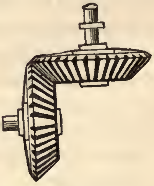


Fig. 12.
BEVELED WHEELS.

In all cases of the transmission of motion in machinery by means of wheels having projections engaging with each other, the projections are called *teeth* when they are formed by cuttings in the *substance of the wheel itself*, as in the works of a watch. But when they are formed of some other substance—of iron, for instance, or a harder kind of wood inserted in a wooden wheel, as is common in millwork, they are called *cogs.*

Sometimes, instead of two wheels that engage with each other by means of teeth or cogs, it is a wheel and straight bar that are geared together, by which means a rotary is

Fig. 13.
RACK AND PINION.

converted into a rectilinear motion. This arrangement, shown in Fig. 13, is called a rack and pinion. In Fig. 14 there is rack-work on each side, the pinion being in the centre, and the pinion has teeth only upon one half the circumference. The effect, as will be seen by an attentive consideration of the figure, will be, that if the pinion has a *direct* motion—that is, a motion in the direction of the hands of a watch, when the toothed part of it engages with the rack-work on the lower side, it will move the frame toward the left, and then, when this same toothed part comes round to the upper rack-work, it will throw it to the right. Thus a continued rotary motion will be transformed into a reciprocating rectilinear one.

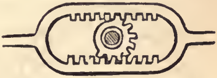


Fig. 14.
RECIPROCATING MOVEMENT.

Sometimes cogs or teeth are placed on the *interior* of the circumference of a wheel, in which case the action when in gear is the reverse of that which is produced when they are on the outside. For instance, the lower of the two small wheels in Fig. 15 being the driving-wheel, its teeth work into the teeth which extend half round the centre-piece of the large wheel, until, when they come to the end of these teeth, they engage with the teeth on the internal surface of the *outer rim* of the wheel, and carry the large wheel in the contrary direction. Thus the continued and equable motion of the driving-wheel will carry the large one round slowly and with great force through half

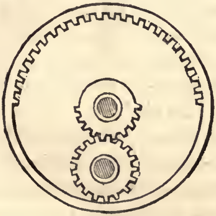


Fig. 15.
FORWARD AND REVERSE MOTION.

a revolution, and then bring it back again with a swift motion and small force to its first position.

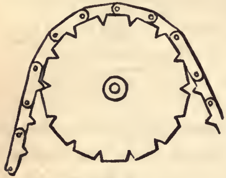


Fig. 16.
CHAIN AND PULLEY.

The communication of motion by means of belts or bands, and by toothed wheels, would seem to be essentially different in their nature, and yet they may be in a measure combined, though in such case the band must take the form of a chain of some sort, with iron projections to engage with recesses formed to receive them in the circumference of the wheel, as in Fig. 16, or with openings to receive teeth or cogs formed in the circumference of the wheel, as in Fig. 17.

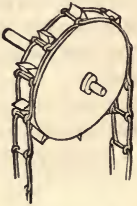


Fig. 17.
ANOTHER FORM.

In some cases, however, as in that of the barrel and fusee in the works of a watch, a flexible chain is used to transmit motion without any teeth, either upon the pulley or upon the chain, the nature of the connection rendering such an arrangement unnecessary. The case of the barrel and fusee, already shown, is an example of this kind.

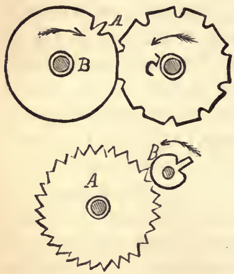


Fig. 18.
SINGLE-TOOTHED WHEELS.

In Fig. 18 we have an example of *single-toothed* driving-wheels. The effect is evidently to impel the driven wheel only one step in its movement at every revolution of the driver. Thus, while the latter revolves with a continuous and equable motion, the former advances by a series of impulses, with intervals of rest between. There are a great many cases in which devices of this kind are employed.

An *eccentric* wheel is a wheel revolving about a point which is not in the centre of it, so that it bulges out, as it were, on one side. If such a wheel is inclosed within another, which is connected with a bar that is so arranged as to allow of a sliding motion from side to side, the eccentric, or *cam*, as it is sometimes called, will give it a *reciprocating lateral* motion, as shown in Fig. 19, where the wheel in the centre, revolving on the axis on the right side of it, will, as it revolves, push the circular frame surrounding it, and the bar seen on the left connected with the frame, first one way and then the other, as the bulge goes round.

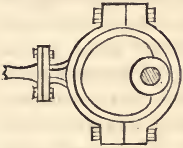


Fig. 19.
ECCENTRIC, OR CAM.

Curious examples of the purposes which eccentric wheels are sometimes employed to subserve are given in Fig. 20. In the first example a single cam works the upper jaw of a pair of shears for cutting off bars of iron, as shown in a previous engraving; and in the second there are two cams upon the same axis, which alternately raise and depress the bars on which they act, for the purpose of opening and closing different valves alternately with each other, or for producing any other alternating motion.

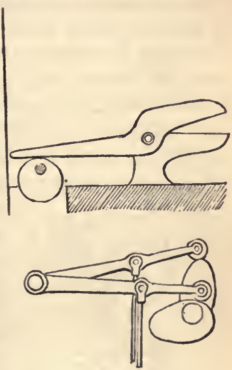


Fig. 20.
ACTION OF THE CAM.

Sometimes teeth are formed upon wheels so as to act as cams, or, rather, as portions of different cams arranged around the same axis, as shown in the arrangement for working a trip-hammer in Fig. 21, where the ponderous trip-hammer A, turning on the joint seen at the right, is lifted by the series of cams arranged around the axis B. The hammer is raised by the teeth as the axis revolves, and let fall in a succession of blows upon the mass of hot iron seen on the anvil at the left. Teeth operating in this way are sometimes called *wipers.*

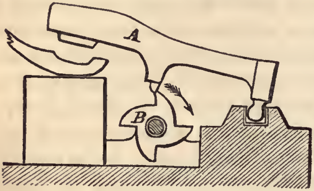


Fig. 21
WIPERS.

In Fig. 22 we see another form of what are called *wipers*, which, by the rotation of the axis to which they are attached, in the direction of the arrow, impel the frame surrounding them alternately to the right and to the left, thus producing a reciprocating rectilinear motion from a continuous rotary one. The same effect is produced by a different contrivance, involving the use of what is called a *crank-pin.* The crank-pin is seen in section near the right-hand margin of the wheel, and as the wheel revolves it moves up and down in the groove, or "slot," as it is called, in the arm, at the same time carrying the arm alternately to and

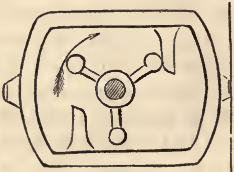


Fig. 22.
WIPERS AGAIN.

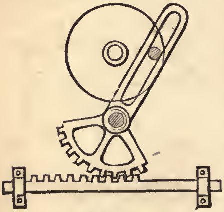
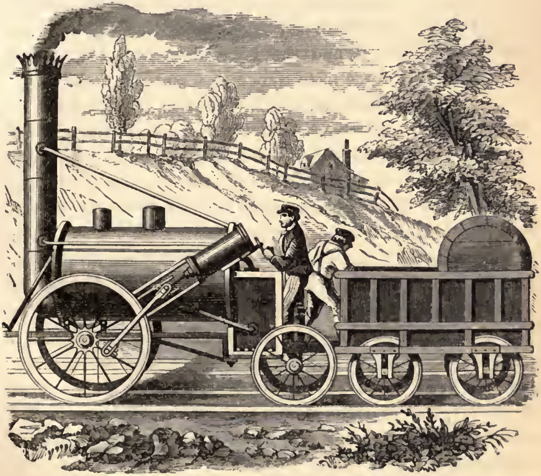


Fig. 23.
CRANK-PIN.

fro, and thus communicating a reciprocating rectilinear movement to the bar below by means of the rack and toothed *section*—that is, the toothed portion of a wheel.

It is precisely the reverse of this effect that is often required—that is, a reciprocating rectilinear motion is to be converted into a continuous rotary one—and this is almost always the case in the use of the steam-engine for supplying the force required. In the case of the locomotive engine, for example, the movement of the piston to and fro is made through the medium of a crank, to turn the driving-wheels by which the train is drawn along the track. The connection of the machinery by means of which this effect is produced is usually observable by the by-stander in any locomotive as seen upon a track; but it is very plainly



THE FIRST LOCOMOTIVE.

manifest in the preceding engraving, representing the simpler form of machinery that was employed when the system was first introduced.

By proper combinations of these and many other elements of machinery, an infinite number and variety of effects may be produced as the exigencies of the work to be accomplished may require. Indeed, there are some contrivances that seem to be almost endued with intelligence, as they find out for themselves, as it were, what is required, and vary their action as the exigencies of the case vary. This kind of action, which takes effect in one way or another, or at one time or another, as the emergency requires, is called *automatic.* An example of it is shown in Fig. 24, which represents what is called the governor of a steam-engine. The horizontal axis below, and the beveled gearing, bring the force from the engine, and cause the vertical axis carrying the two heavy wheels to revolve. The upper end of the vertical axis is connected with the valve which admits the steam from the boiler to the engine. When the machinery goes too fast, the balls, by too rapid revolution, spread as they revolve, and draw down the bar above by shortening the diamond-shaped frame between the balls and the bar, and thus partially closing the valve and diminishing the flow of the steam. On the other hand, when the machinery goes too slowly, the balls fall a little way together, and push up the bar, so as to open the valve a little more. Thus the contrivance watches, as it were, the passage of the steam, and, by an automatic movement, checks the supply when it is too great, and increases it when it is too small.

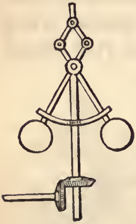


Fig. 24.
AUTOMATIC ACTION.

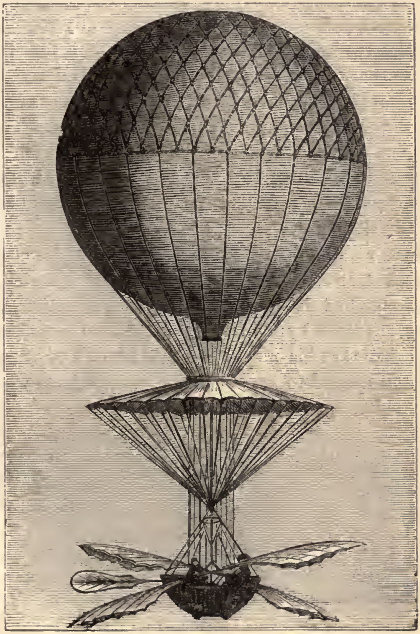
The examples given in this and the preceding chapter will be sufficient to give the reader some general idea of the nature and character of the contrivances by which motion is transmitted in machinery, and changed in certain respects by the mode of its transmission. They are not sufficient, however, to convey any idea of the immense number and variety of these contrivances. The number of combinations, each distinct in certain essential points from any other, as described in books, or exemplified in models in the collections of patent-offices, or as actually working in machine-shops and manufactories all over the country, is beyond all calculation, and is increasing now every year faster than ever before. From five hundred to a thousand new contrivances are brought forward every month in the patent-office at Washington, a very large proportion of which are new combinations for changing the character and action of mechanical force by the mode of its transmission, so as to take it in a simple form from the piston-rod of a steam-engine, or the walking of a horse, or the turning of a crank by the hands of a man, or the rotation of a shaft near the ceiling in a work-shop, and so dividing it, and diverting and employing the various portions into which it is divided, as to accomplish the most minute and complicated operations. Every reader of this book will find innumerable examples of this kind of action all around him, and the illustrations given in these chapters will perhaps lead him to take an interest in them, and aid him in understanding them.

But the main thing to be learned from this chapter is the fundamental principle that by none of these contrivances, nor by any conceivable ones, can force be increased or diminished in amount. What is imparted to the machine at the beginning may be changed in form and action, but it can not be increased or diminished in quantity. It can be accumulated or it can be dispersed; a weak rapid motion can be changed by the manner of transmitting it to a slow and powerful one, or a great power moving slowly may be made to communicate great speed with small power, but the amount will be in both cases the same.

When, therefore, we hear of any new mechanical contrivance, the first and most important inquiry is, From what source is the force to come by which it is to be driven? There have been a great many attempts, for example, to contrive wings by which a man might fly. The engraving gives a representation of one of them. The difficulty with this and with all other similar contrivances is not that the wings, if worked with sufficient rapidity and power, would not suffice to sustain the weight of the man, but that there is not in the action of the muscles of the human arms and legs *force enough to work them* with that degree of rapidity and power. Birds possess—in the muscles of the breast,

WINGS WITHOUT FORCE TO WORK THEM.

by which the wings are moved, and in certain peculiarities of the digestive organs which fit them for drawing abundant and rapid supplies of force from their food—the requisite strength for lifting themselves from the ground and impelling themselves forward by strokes upon the air; and if the structure of the human body were such as to give man the command of a force as great in proportion to his weight as that which the hawk or the eagle wields, in-



MORE WINGS WITHOUT FORCE.

genious mechanics would find very little difficulty in contriving wings by which he could apply it.

It is the same in respect to navigating the air by means of a balloon in any other direction than that of the wind. Many people think that the thing to be discovered is some method of *steering* the balloon. But there is no difficulty at all in the steering—that is, in directing any particular point of it in the way we wish it to go. The difficulty is in the want of *force* to make it go forward in that way. It is *propelling*, not *steering* power that is really required.

Let the reader, then, fix in his mind as a fundamental principle that every human mechanism must derive all the force it can possibly bring into action from some one of the external sources of supply existing in nature. This the mechanism can not increase, nor can it diminish it, but must pass it all on to be expended in the work done, or diffused among the surrounding substances in the heat produced by friction.

If there were two new plans proposed for the construction of a cotton-mill, in one of which there was a claim that the inventor had discovered a mode of generating, out of nothing, the force by which the mill was to be driven, and in the other that his machine would make out of nothing the cotton needed to supply it, the two projects would be exactly equal in absurdity.

CHAPTER VI.

THE MILL.

One morning, toward the spring of the year, John, on his way to school, finding that he had a little time to spare, went round by the way of Lawrence's shop to see what his cousin was doing. He found him engaged in cutting out little squares of thin glass with a diamond, for the purpose of making slides for his microscope. After remaining and talking with him a few minutes, taking out his watch frequently as he did so, so as to be sure not to stay too long, he finally said,

"Well, good-by, Lawrence."

"Must you go?" asked Lawrence.

"Yes," said John; "I make it a point always to be at school *on time*."

So Lawrence bid him good morning, and he went away.

Just as he was going out of the gate, however, John heard Lawrence's voice calling to him. He stopped to hear what his cousin had to say.

"I want you to take a message for me to Rick."

"Well, what is it?" asked John.

"Tell him I should like to have him inquire of some farmer—if he knows any farmer—what is the very hardest and toughest kind of timber that grows in the woods about here."

"Well," replied John, in a doubtful and hesitating manner, "I will ask him, but I don't believe it will do any good."

"Tell him that if he can find out what is the best wood," added Lawrence, "and will go with me and get some, and will help me to turn some bats out of it—say four—he shall have half of them."

"Well," said John, "I'll tell him."

So John walked away.

That day, at recess, John, seeing Rick standing by himself, apparently waiting for somebody or something, recollected his message, and called to him.

"Rick," said he, "I've got a message for you from Lawrence. He wants you to ask some farmer what is the very hardest and toughest wood that grows about here, so as to get some of it to make bats of."

Rick stared at him a moment with a stupid expression of countenance, and with his hands in his pockets, and then said, in a sulky and almost contemptuous tone,

"*I* don't know any farmer about here."

John paused a moment on receiving this rebuff, eying Rick with a ludicrous expression of uncertainty in his countenance, as if he was at a loss what to do or say next. At length he added,

"He says if you will find out what is the best wood, and will help him to get it and to make three or four bats, you shall have half of them."

To this Rick made no reply, but only stared at John in a bewildered manner; and John, after waiting a moment, turned round and went slowly away, saying to himself, "I knew it wouldn't be of any use."

Very soon the person that Rick was waiting for came, and Rick went away with him, and thought no more for a time about the message he had received. That afternoon, however, he happened to see a farmer coming into the yard at Morningside with a load of wood. The farmer stopped at the end of a long wood pile, and began unloading it. Seeing this man and his load of wood reminded Rick of his message; and as it just then occurred to him, too, that it would be a nice thing to have two new bats of a specially hard wood, he determined to take this opportunity to make the inquiry. So he called out to the man,

"Say! you mister! what's the hardest kind of wood that grows hereabouts?"

The man looked up a moment from his work, and, seeing that it was Rick, did not answer, but went on unloading his wood. Rick's character as a mischievous and ugly boy was well known to all the people that came to Morningside, and every one wished to have as little to do with him as possible. The farmer thought that Rick, in asking the question, had some plan of quizzing him, or playing upon him some kind of trick, or offering him some impertinence, so he said nothing.

"Say!" repeated Rick; "tell us, won't ye?"

The man, being very sure that Rick was not serious in his inquiry, but was designing, in some way or other, to make a fool of him, had a great mind to pay him in his own coin, and answer "poplar," which is perhaps the very softest and weakest wood that grows, and the most unsuitable for bats, or axe-handles, or wedges, or any thing of the kind. But he thought that, on the whole, it was best not to excite Rick's ill will, and so he said, after a moment's pause, but without stopping his work,

"Well, I suppose hornbeam is about the hardest wood that grows hereabouts."

Rick, on hearing this answer, stood for a moment with his hands in his pockets staring at the man in a somewhat stupid manner, while the farmer went on quietly with his work of unloading his sled, until presently Rick asked,

"Say! how shall we know hornbeam when we see it?"

"Know it?" repeated the farmer, still going on with his work; "why, by the looks of it."

Rick stared at the man a moment more, as if hardly knowing whether this was meant to be a serious answer or not, and then finally asked,

"Yes; but how does it look?"

"How does it look?" repeated the farmer; "why, like hornbeam."

If Rick had been accustomed to any nicety of observation, he would have perceived a faint semblance of a smile lurking at the corners of the farmer's mouth as he said this; but, though his senses had been trained to extraordinary accuracy in watching the approach of a ball through the air, and in so regulating the swing of the bat that it should strike the ball at the precise instant and at the precise distance from the end of the bat required for producing the greatest effect, his perceptions were far from being quick in any other respects. So he attributed the farmer's absurd replies to boorish stupidity, and turned away muttering to himself, "What a fool!"

On reflecting upon the subject of Lawrence's proposal, Rick concluded that he should like two new bats very much, especially if they were made of a particularly hard kind of wood, and accordingly, after school, he ran to the gate, and called out to John as he was going down the road toward home. John looked around to see what was wanted.

"Tell him," said Rick, "it's hornbeam, and I'm agreed to go."

In consequence of this and subsequent arrangements, on the next Saturday Lawrence, Rick, and John met at an appointed place of rendezvous, and set out on an excursion in search of some hornbeam. They had provided themselves with a handsaw and a small axe, their intention being to saw off the hornbeam, if they should find any of the right length for bats, and to hew out the sticks pretty nearly to the right size, so as to have as little useless wood as possible to bring home.

It was a pleasant day in March, and there was still a good deal of snow upon the ground, especially in the fields and woods, but it was well worn down in the roads. After going on for some distance, taking a direction which led toward a region of forests, they came to a mill, and Lawrence said that, as the mill-men would be likely to know where they could find hornbeam growing, he would go in and inquire of them. But before he went into the mill the attention of all three of the party was attracted to the other side of the stream on which the mill stood, where some workmen were making a sluice-way, or flume, to convey the water down to a site below, where it seems a new mill was to be built.

There were two gangs of men at work upon this sluice-way. One of them was employed in bailing out the water from a part which had already been excavated, and pouring it into a tub which stood upon the top of the bank, from which tub it flowed into a long wooden conduit, by which it was conveyed down into the mill-stream below. The others were hoisting up a great stone from the bottom of the excavation by some kind of hoisting apparatus, formed of pulleys and ropes, and worked by a windlass at the foot of it.

The boys, being somewhat interested in these operations, went over to watch them for a few moments, and presently they all three went down the bank, and, finding a good seat there in a warm, sunny place, they sat down to rest themselves and talk.

"There," said Rick, pointing as he spoke at the men who were raising the big stone, "you said there could not be any gain of force in machinery; but see how those two men lift that big stone by the tackle and fall. They

MAKING A SLUICE-WAY.

could not lift a stone one quarter as big by their own strength. It is the tackle and fall that does it. The force is in that."

"That is very true," said Lawrence; "at least it is very true in a certain sense. I don't see how it would be possible for two men to get so big a stone out of such a deep ditch without a tackle and fall, or some other such contrivance."

The first thing to be done when you undertake to give a person any instruction, and especially when you attempt to correct any mistaken ideas he may have formed, is to bring his mind into harmony with your own by seeing and acknowledging whatever of truth, or semblance of truth, there may be in the erroneous opinion he expresses; for in almost all the beliefs and opinions which people hold there is some truth, or at least some semblance of truth, and this is really what the mistaken person sees and assents to. Whenever, therefore, we wish to make a person see a thing as we see it, the first step we have to take is to see it ourselves as he sees it.

"The windlass and the tackle and fall help the men a great deal, it is true," said Lawrence, "but, after all, they only help them by storing and concentrating the force which the men put into the apparatus, and not by really increasing it. You see they are turning the windlass by a long-handled crank. How long do you think that crank is, John—I mean the *arm* from the centre out to the handle?"

John estimated the length at about a foot.

"That's about right, I should think," said Lawrence. "Well, double the arm would be the diameter of the circle that the hands of the men move through in turning the windlass once round; and as the circumference of a circle is about three times the diameter, the men's arms must make a sweep of about six feet at every turn, and in ten turns they must carry the handles round and round a distance of sixty feet, for ten times six, you know, Rick, is sixty."

Rick assented.

"And now," said Lawrence, "let us notice how high the stone is at a particular moment, and then wait till the men have turned the windlass ten times—that is, till they have exerted their strength through a space of sixty feet, and then see how high the stone has been raised. You count the turns, Rick."

So Rick counted up to ten, and both the boys were surprised to see how little the stone had ascended.

"So, you see," said Lawrence, "that, in one sense, there is no real *gain* in the employment of such machinery. In another sense there is a gain—that is, there is an advantage, but there is no actual gain of force. All the force which the men can impart by a movement through sixty feet of space is concentrated in a movement of the stone through one or two feet. So you see that while there is really a great gain, in the *sense of advantage* or benefit, in the use of such a contrivance as this, the advantage consists in concentrating and accumulating the force which the men exert, and not at all in increasing the amount of it.

"And now," continued Lawrence, turning the conversation to another point, not wishing to fatigue Rick's mind by confining his attention too long to one train of thought, "look at that tub upon the top of the bank that the other men are pouring the water into from the bottom of the ditch. The water, you see, runs out through an opening near the bottom of the tub, and so down the spout into the stream."

"What do they have a tub and a spout for?" asked Rick. "Why don't they pour the water right out upon the ground, and so let it run down the bank."

"Perhaps they don't wish to have the bank washed away," replied Lawrence, "so they place a wooden spout there to convey the water safely over it down to the stream below. And I suppose that they have a tub at the top, because it is so much more easy to pour the water into a tub than it would be to pour it into the end of the trough. They require some kind of receptacle for it to take it by pailfuls as they dip it up, and deliver it in a steady stream into the spout. Don't you see that, though the men pour the water in at intervals into the tub, it flows in quite a regular stream out of the lower end of the spout where it falls into the river?"

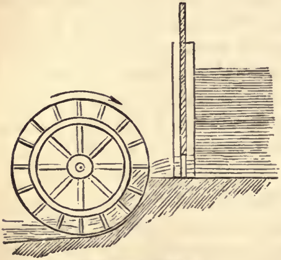
Lawrence then went on to explain that the whole arrangement, in its action upon the water, was quite similar to that of the grindstone in its action upon force. The grindstone receives the force in a succession of separate impulses given to it by the weight of the foot upon the end of the treadle at regular intervals, but the stone, by its weight, receives and stores this force, and delivers it at the outer margin of the stone, when the tool is pressed upon it, in a steady and continuous action, just as the arrangement of the tub and spout receives the water in a succession of separate pourings from the pails, and delivers it at the end of the spout in a steady and continuous flow.

"And just as there can not be any more water," he added, in conclusion, "to flow out at the end of the spout than is poured into the tub from the pails, so there can not be any more force exerted by the grit of the surface of the grindstone upon the tools, in its total amount, than is put into it by the successive impulses of which the weight, or, rather, the pressure of the grinder's foot upon the treadle, imparts to it. And so with all other machinery. It can only use force supplied to it. It can not create any."

This effect of producing a steady and equal flow of water from a source furnishing it in a series of distinct and intermittent supplies is sometimes produced in a very different manner from that exemplified by the tub and wooden channel in this case. The most common mode is by what is called an *air-chamber*, which consists simply of a strong metallic receptacle for confined air, which receives and stores the impulsive force by its elasticity, and delivers it in a comparatively steady flow. They use this contrivance in the case of fire-engines, whether worked by hand or by steam. It is necessary, for the most efficient action of the engine in putting out the fire, that the water should issue from the pipe in a steady stream, and not in a succession of jets. Now, as the action of the men in working the brakes, and that of the engine in impelling the piston-rod, drives the water forward by a series of separate impulses, it would be delivered from the pipe in a succession of jets were it not that there is always an air-chamber of copper or brass—usually to be seen rising above the machine in the form of a big inverted bottle—which is connected by its mouth at the lower end with the pipe which conveys the water, so that the excess of force given by each succeeding stroke of the brakes, or of the piston, is absorbed in condensing the air in the air-chamber, and this excess of force is given out again in the intervals between the strokes. Thus what would otherwise be a succession of jets is transformed into a steady stream. The action is exceedingly rapid, but the effect is very sure and very decisive.

But to return to our party. While they sat looking at the water as it glided down the long spout, and issued in quite a little cascade at the bottom, John said that he should have liked very much, when he was a boy, to have such a fall as that to put in a wheel for a water-mill.

"You might put in quite a nice little wheel there at the lower end of the spout," said Lawrence—"an undershot wheel."


UNDERSHOT WHEEL.

"What is an undershot wheel?" asked John.

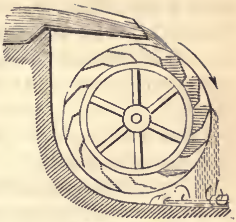
"It is a wheel," said Lawrence, "so made and so placed that the water shoots under it, and causes it to revolve by the force with which it strikes against the floats or paddles projecting from the wheel. But a wheel in such a fall as this would not revolve with much force. It would be a pretty thing enough for a plaything, but you could not make it do much work."

The degree of force which a stream of water exerts, or, rather, is capable of exerting in all such cases as this, depends upon a very simple principle, which is not only of fundamental importance in all the calculations of millmen and engineers, but is so simple that it is very easily understood by any young person who will attentively consider it a few minutes. The force depends in its amount on two elements—first, the *quantity of water;* and, secondly, *the height from which it falls.* And it makes no difference whether it falls perpendicularly or flows down an inclined plane, provided it encounters no resistance in coming down the plane. It is true that, practically, it must in all cases meet with more or less resistance from the friction upon the plane or upon the sides of the channel which confines it. In such a case as this which Lawrence was speaking of, for example, the friction of the water upon the sides of the spout would retard the motion, and so diminish the force to a very perceptible degree; and in the case of a brook running over a stony bottom down a mountain gorge, the whole of the falling force of the water would perhaps be spent as fast as it was generated, so that the water would impinge against the stones which lay in its bed at the bottom of the descent with no greater force than it did against those at the beginning of it.

But in all cases where the energy of the action is not thus spent in friction or in collisions by the way, the force with which it strikes at the bottom of any fall, or that with which it issues from any opening at the bottom of a receptacle holding it, depends simply on the quantity of water which thus flows or issues in a given time, and on the height from which it falls, or, in the case of flowing from an orifice, on the depth or distance of the orifice below the surface. This makes the calculations in respect to the absolute theoretical force of water used for driving machines very plain and easy for millmen and engineers. They have only to consider the quantity of water—that is, the weight of what falls or flows out in a given time—and the height from which it falls, or the depth which produces the pressure under which it issues.

Thus, in the case of the tub and the spout which the boys had been observing, if the bank had been ten feet high, and if each man had dipped up two half pailfuls in a minute, the force that the stream would exert upon John's supposed water-wheel at the bottom would be the force of *two pailsful* of water falling through ten feet, provided, of course, there had been absolutely no friction or other obstruction by the way.

Lawrence did not attempt to explain this fully to Rick and John, for he thought that Rick was not probably far enough advanced in his capacity for understanding generalizations of this kind to take an interest in such a train of thought. He explained it afterward to John, who was old enough and far advanced enough to take a great interest in it. He explained to him that, as the force with which the water shot under a wheel was the same as that which it would exert by its weight in falling from the same height directly down, there was no difference in theory between employing the force of the water to act by its impulse in striking the floats of the wheel on the lower side of it—as shown in the engraving of an undershot wheel—or by its weight in descending directly in boxes or buckets formed in the circumference of the wheel to contain it, as is shown in the case of what is called an overshot wheel, such as is represented in the following engraving.



OVERSHOT WHEEL.

But, though there is no difference in theory, that is, in the actual *amount of force developed* in the two cases, there is a great difference in the availability of the two methods of employing it, making it much better in some cases to employ an overshot, and in others an undershot wheel.

After a short time Lawrence and the boys rose from their seats and went up the bank. Lawrence went into the mill to make his inquiries, while John and Rick stood on the shore above the mill to look at the dam and the water flowing over it, and the great pond of still water which spread from side to side, and extended far up a winding and wooded valley. Presently Lawrence came out and said he had found out which way to go. So they went on along the road, and as they went Lawrence thought that he would try the experiment of presenting to the boys a train of thought in respect to force, with a view of seeing whether he could lead Rick to take an interest in it by means of making the images involved such as Rick could easily picture to his imagination.

"Suppose," said he, "that there was a thunder-cloud up in the air that contained water enough, if it was all collected, to make a hundred hogsheads, and that it was at the height of—how high do you suppose a thunder-cloud commonly is, Rick?"

Rick said he had no idea.

"We often read of mountains eight or ten thousand feet high," said Lawrence, "and of thunder-clouds half way down their sides. We will suppose, therefore, that the thunder-cloud is five thousand feet high; that is not far from a mile. Then the whole amount of force which would be developed by the shower, from the cloud where it begins to fall down to the sea, which all the water reaches at last, would be that of a hundred hogsheads of water falling a mile."

"But there could not be any hogsheads of water at all in a cloud," said Rick.

"No," said Lawrence, "not in that form; but there might be drops enough to make a hundred hogsheads; or, if there were not drops enough already formed, there might be vapors enough to form them."

"Well, go ahead," said Rick.

"Now, as there are one hundred hogsheads of water a mile high in the air, there is stored in them, or held by them, as it were, in reserve, as I was saying, a falling force represented by the weight of all *that water falling a mile*, which is something enormous. Now let us follow the water in imagination as it comes down, and see what becomes of all this force."

Lawrence was interrupted in the work of presenting his "train of thought," as he called it, by observing that Rick had stopped by the wayside, and was looking up very intently into an evergreen tree which was standing there near the road. He and John stopped too.

"What is it?" asked John.

"I believe I see a bird's nest," said Rick.

"Never mind," said John; "it can't be any thing but a last-year's bird's nest, at any rate; it is too early for any of this year's, so come along."

"I mean to climb up and see," said Rick.

"Yes," said Lawrence, "I would if I were you; it is well to be sure; and, besides, I want to see how well you can climb."

So Rick climbed up into the tree, and found that it was, as John had predicted, nothing but an old nest.

"I'm glad I went up, at any rate," said Rick, as he came down.

Lawrence was glad of the incident too, for it showed him how little interest Rick took in what he had been saying. The gaining of any new ideas on the subject of force had less attraction for him, it seemed, than even a last-year's bird's nest! And though he would have been better pleased if Rick had evinced some interest in what he was saying, yet still, since he did not feel any interest, he wished to know that fact. He was glad to have any thing occur to make known to him what the true state of the case was.

Just as Rick had descended from the tree, and was brushing off the dust and the fragments of bark from his clothes, a sled loaded with wood appeared, as it was coming along the road. A man was walking by the side of the oxen, and, as he came nearer, he proved to be the same farmer that had given Rick such equivocal answers about hornbeam. His name was Berry, and his house was very near the woods to which Lawrence had been directed at the mill.

"Ah!" said Lawrence, "here comes Mr. Berry. The place where we are going is on his land, and he will tell us exactly where to go; besides, I was intending to stop at his house and ask his permission to cut down one of his hornbeam-trees."

"You won't get any thing out of him," said Rick; "he's an old fool."

But Mr. Berry proved himself not to be a fool at all, on coming to the spot. When he saw that the leader of the party of young people was Lawrence—whom he knew very well, in some degree personally, but more by reputation—

and observing that Lawrence wished to speak with him, he stopped, allowing his oxen, however, to go steadily on with their load.

He told Lawrence exactly where to go on his land, and gave him permission to cut what hornbeam he wanted.

"If you will call at my house," said he, "and take my boy Charley along with you, he will show you just where to go."

Lawrence thanked him, and said he should be glad to do so, and then Mr. Berry went on. Very soon, however, he stopped again, and, turning round, said,

"Look here, Mr. Wollaston! what you cut in the woods will be green, and it will take some time to season it. I have got some in my loft all ready—some that I got out for axe-handles; I keep a good supply on hand, so as to have it well seasoned when I want it. If you prefer it seasoned, you can take some of mine—as much as you want—only put in its place the same amount of green, to keep my supply good; it will get dry by the time I want any."

Lawrence thanked Mr. Berry, and then he and the boys went on. They found Charley, and he—first showing them the store of seasoned hornbeam sticks which Mr. Berry had in his loft, among which the boys found several of the right size for their purpose—led the way into the woods. Lawrence, under his direction, soon found some hornbeam-trees, the stems of which were large enough to be sawed or split in two through the centre, and to furnish wood sufficiently thick to form a bat out of each half. Lawrence concluded to cut wood enough for four bats, and to exchange two of them for two seasoned pieces from Mr. Berry's stores.

He had, however, just begun the work when Rick's attention was attracted by a large gray squirrel which he saw running along a log.

"My eyes!" he exclaimed; "there's a gray squirrel—a splendid fellow! See! see! He's worth—oh, if I could only catch him!"

"Never mind him," said John; "you can't possibly catch him—not alive."

"If I can't get him alive," said Rick, "I can get him dead. I want his skin. Give me a club."

So saying, he began to look about the ground in a state of great excitement in search of a club. He soon found a stick, and, seizing it, he ran off after his prize. The squirrel bounded from the log to the trunk of a tree, ran up the tree to a branch, crept out to the end of the branch, and leaped across into another tree, and from that to another, and another. Rick followed him in a state of great excitement. There were many evergreens in that part of the wood, the foliage of which was so dense that Rick, in the eagerness of his chase, soon disappeared from view, and they saw him no more. He did not return.

In the mean time Lawrence and John went on with their work. They cut down the tree which they had selected, and from it, by means of the small axe and the saw, they fashioned, in the rough, four pieces of wood of suitable form and size to make either bats or axe-handles, as might be required. Returning then with Charley to Mr. Berry's house, they exchanged two of their pieces for two of the same size that were seasoned, and then set out for home.

CHAPTER VII.

FALLING FORCE.

As these books are not intended for children, nor even for boys as old as Rick unless their thinking and reasoning powers are much more fully developed than his were, it is to be hoped that most of the readers of it may feel some interest in hearing Lawrence's explanation of the phenomena attending the progress of the vast quantity of water sometimes contained in a cloud, in its course from the sky to the tops of the hills and mountains, and from the tops of the hills and mountains to the sea. The substance of his explanation, as he made it to John while they were walking along together on their way home, was as follows:

If we suppose, as Lawrence did, in fact, that the weight of a hogshead of water is two hundred pounds, the hundred hogsheads would weigh twenty thousand pounds; and if we also suppose the height from which it would fall—that is, the distance from the height of the cloud to the level of the sea—to be five thousand feet, the whole amount of falling force would be one hundred millions *of foot-pounds!*

But what is a *foot-pound?* It is the force generated by the falling of one pound one foot. Take a cannon ball, or a stone, or any other heavy substance weighing *one pound*, and, holding it *one foot* above the table, let it drop. The force imparted to it by gravitation during its fall, and which has to be extinguished as mechanical force when it strikes the table, leaving out of view for the present the resistance of the air, is one *foot-pound*—that is, the falling force of *one pound* through a space of *one foot.* If you hold your hand upon the table and let the weight descend upon it, your hand sustains a blow of one foot-pound.

If you throw a pound ball, or a stone weighing a pound, against a wall so that it strikes the wall with precisely the same force that the falling ball under the above-mentioned conditions would strike a table, the force with which it strikes is one foot-pound.

On the same principle, if the mass of stone or iron let fall weighs *two* pounds, the force developed is two foot-pounds; and also, if the one pound weight is let fall *two feet*, the force generated would be two foot-pounds. If it falls one hundred feet, the force generated is one hundred foot-pounds.

And inasmuch as the force imparted by gravitation to a descending weight through a given space is the same as that which would be *abstracted from one ascending* through the same space, it requires an upward force of one hundred foot-pounds—leaving, as before, the resistance of the air out of the account—to throw a pound ball up one hundred feet.

If a ball-player has a ball weighing a quarter of a pound, and knocks it with a force sufficient to cause it to ascend perpendicularly a hundred feet, the force imparted by his blow is that of twenty-five foot-pounds.

Such is the mode by which forces of this kind are denoted among English-speaking nations. On the Continent of Europe, where the French language extensively prevails, the unit of length being the *metre*, and that of weight being the *kilogramme*, the unit employed for denoting this kind of force is the *kilogrammetre*, which, of course, means the force of one kilogramme falling through a space of one metre. Now, as a kilogramme is a little more than twice the weight of a pound, and as a metre is more than three times the length of a foot, the French kilogrammetre is more than six times the English foot-pound.

In the above examples the resistance of the air is left out of the account. This resistance would be very small in the case of a ball of iron falling one foot upon a table or upon the ground, but it would be much greater in the case of a ball of wood or of cork which should have the same weight; for the ball of wood or of cork, in order to weigh the same as the ball of iron, would necessarily be many times as large, and, consequently, have to encounter and displace a much larger quantity of air. Now the resistance of the air in such a case is in proportion to the amount displaced to open a passage for the falling body, and to the surface exposed to friction along the sides of it. In the case of small masses of iron or stone, therefore, but a very small part of the falling force would be absorbed by the air, while in the case of very light substances, such as feathers or flakes of snow, almost the whole of the force imparted by gravitation would be absorbed as fast as it is generated, so that such substances always descend with a very slow motion. The force flows out of them, as it were, as fast as it is received, and so their motion is but little accelerated. That the resistance of the air is the real cause of the slow descent of such bodies is proved positively by the fact that when the air is removed, as it can easily be, from a tall glass jar, the lightest substances are found to fall as swiftly, and to strike with the same force in proportion to their weight, as heavy ones; so that the force with which a pound of snow in flakes—which descend so gently *through the air*—would, if the air were not present, strike the ground with a force which, combined, would make exactly *one foot-pound.*

The reader will now understand exactly what Lawrence meant when he said that in the whole descent of one hundred hogsheads of water from a height of five thousand feet—which is about one mile—above the level of the sea, down to that level, a force of one hundred millions of foot-pounds would be generated.

Let us now follow the course of such a mass of water in such a fall, and see exactly how this force is disposed of.

While the water remains in a state of vapor it may be actually lighter than the air, and so have no tendency to fall; or, rather, to speak more accurately, whatever tendency it may have toward the earth may be counteracted by a slightly greater weight of the air beneath and around it tending to buoy it up. As the vapor begins to be condensed, however, and to form minute misty drops, a tendency to fall is at once produced, for liquid water, however minute are the masses of it, is heavier than the air; but when the masses are very minute this tendency is almost overpowered by the resistance of the air, and may be entirely overpowered if the currents of air in which they are floating have a slightly ascending motion.

The reason why very minute globules of water like those of a mist or a fog tend to fall so much more slowly than larger ones like those which form drops of rain, is because they have so much more surface in proportion to their weight, and the resistance of the air to a body falling through it is, in a great measure, proportioned to the surface; and just as it would take more leather to cover four one quarter pound balls than to cover one ball of the weight of a pound, so a million of drops, each one containing a millionth of a grain, would present a vastly greater surface to the air to retard their descent than a single drop containing the whole quantity of water in one.

As, however, the minute drops increase in size by additional condensation, or by uniting with each other so as to bring two or more into one, they begin slowly to descend. At first they expend all their falling force in overcoming the resistance of the atmosphere—that is, in pushing the particles of the atmosphere out of the way; or, to express it in more philosophical language, the motion which is generated in them by the falling force is imparted to the particles of air, and so far as there is absolute stoppage of motion by minute frictions and collisions the force is converted into heat, as will be shown more clearly in another chapter.

As the drops grow larger they descend more and more rapidly, increasing all the time in magnitude as they descend, until at length the falling force becomes far more than sufficient to open a passage for them through the air. All this surplus of force remains in them, of course, to be delivered on the ground below, when they reach it, so that, when at length they fall upon the ground, they do so with all the falling force which has been generated by their descent from the clouds, except what they have distributed through the air in heating it and imparting motion to its particles on the way.

Let us now suppose that the shower which we are condensing falls upon an elevated tract of land, consisting of hills and mountains of such magnitude that the average height of the land is one thousand feet, so that the water, in the whole of its descent from the clouds, will have fallen, upon an average, *four thousand feet.* So much, therefore, of the falling force of the hundred hogsheads will have been expended on the way, or suddenly extinguished by the impact of the drops upon the ground. This extinguishing of the force is not, as will hereafter appear, an annihilation of it, but only a change of it into another form, namely, heat. At any rate, the water loses it in the form of force, and only retains such a portion of the heat which is developed by the collisions as happens to fall to its share. The falling force of that four thousand feet of descent is gone entirely, which you will find, on making the calculation, amounts to eighty millions of foot-pounds out of the hundred millions of the whole descent; that is to say, four fifths of it, only one fifth of the whole amount remaining to be developed by the falling flow of the water down the mountains to the sea.

Such is the enormous force that a falling shower of this magnitude would exert in its descent to the upland on which it falls, a part being distributed through the air on its way, and a part extinguished as force by the impact of the drops upon the ground.

In the case of a snow-storm, consisting of light fleecy flakes, the largest part of this immense force would be expended in the air on the way; but in case of a rain-shower, consisting of large drops, a very considerable portion of it would be delivered up to the ground at the end of its fall.

But, though eighty millions of foot-pounds of the falling force of the rain has thus, in our supposed case, been dissipated and lost at the time the water reaches the ground, there is still twenty millions more to be developed by the remaining portion of the descent. Let us follow the water in its course, and see what becomes of this remainder.

The little streamlets and rills formed by the rain begin at once to flow down the mountain sides, and to run along the valley, each portion of the water that amounts to a pound in weight developing a force of one foot-pound for every foot of its perpendicular descent. But this force, as fast as it is developed, is given out to the stones, and roots, and other obstructions which form the beds of the brooklets down which it flows.

After descending in this manner from the highland region, rippling among the stones in mountain brooks, or tumbling over long cascades, the water reaches at last the more level country, from which the descent is gradual to the sea. The brooks and rivulets unite together into larger streams on the way, and then finally combine to form a great river, which now flows somewhat smoothly and comparatively slowly toward the sea, with only the force of a gentle descent to urge it along. If, for example, the inclination of its bed was five feet to the mile, every cubic foot of water would have a falling force of five foot-pounds to carry it a mile, which amount of force could only impart to it quite a moderate amount of motion. A boy walking along the bank could perhaps easily keep up with the current which this amount of force would produce. A great part of this force, too, would be expended on the way in the friction of the water along the bank, and in encounters with rocks, snags, roots, and other obstacles which it would meet with in its course, so that after flowing onward for several miles the rapidity of its flow might not be at all increased, and might even be diminished, as it is only the excess of the falling force over the resistance and the friction which can operate to produce an acceleration of the flow.

It would be, moreover, but a comparatively small portion of the water which fell from the cloud that would have found its way to the channel of the river. A large part of it would have remained upon the surface of the ground, adhering to the leaves, the grass, and the soil, and would have evaporated when the sun came out, after the shower was over, and so carried back again into the air, to form the material for future showers. Another part would have gone into the ground, there to be absorbed by the roots of plants, or would have percolated through the strata of sand and gravel, or through the crevices of the rocks, to find its way out again in springs and swamps far below. We will suppose that half of the whole amount reaches the river, and at the place where the river began to flow with a smooth and equable current, the bed of it is five hundred feet above the level of the sea. We then have a weight equal to that of fifty hogsheads that is yet to fall five hundred feet, which is all the force that can possibly be generated by the water of this shower in its whole course from the point we have designated to the sea.

Now, so long as the river flows over an unobstructed bed with a gentle inclination, the falling force comes very slowly into action, and a large part of it is absorbed by the friction of the banks and other sources of diversion. Still, a considerable amount of the force imparted to it by gravitation remains, and bears the water along with a certain degree of momentum, a portion of which may be abstracted and utilized by means of a water-wheel attached to an anchored boat, for example. By this means a kind of floating mill may be worked, and made to carry light machinery by the impulse of the flowing water. This force, however, can not be very great, for it consists of that part only of the force that has been imparted to the waters by its previous fall, which has not yet been dissipated by friction and collisions.

By-and-by, however the river arrives, we will suppose, at a place where, on account of a sudden descent of the land, there is a fall of the waters of perhaps fifty feet in the course of half a mile. Here, of course, there is a sudden and great development of the falling force of the water, shown by the violence with which it tumbles over the rocks along the cascade, and the foam and the spray which it creates by its collisions with them. If we suppose that the quantity of water of our original hundred hogsheads now remaining is one thousand cubic feet, and that this quantity passes a given point at the foot of the fall in half an hour, we should have a falling force of one thousand cubic feet through a space of fifty feet perpendicular height, making fifty thousand foot-pounds for every half hour; and if the flow of the river from waters derived from other rains upon the mountains was continuous, and if all the water flowing down the cascade could be intercepted by a dam and kept up to a level with the top of the cascade, so as to get the whole falling force at once through a gateway in the dam at the lower end of the cascade, the "mill privilege," as mill-men call such a place, would be one of one hundred thousand foot-pounds an hour. It could not be any less, except so far as some portion of the force might be wasted by accidental impediments or by imperfections in the constructions, and it could not possibly, under any circumstances, be more.

Now it is strictly on these principles that all engineers and millwrights make their calculations in estimating the availability of any "mill privilege" as a source of power. It is true that in ordinary cases—that is, in the building of saw-mills and grist-mills on streams of moderate size in the country, men do not usually make any very accurate measurements, nor do they express the results of their calculations often in numbers, or in any other mathematical form; but they are perfectly familiar with the principle—that is, they understand on what two elements the force depends, namely, on the quantity of water that they can command, and on the whole perpendicular height from which it falls or by which it presses. And in all large, expensive, and important undertakings, where skilled engineers are employed to make the calculations and the estimates, the force they have to deal with is often determined from these elements with mathematical exactness, the number of foot-pounds at their command is precisely ascertained, the portion of this which can not be made available, through friction and waste, is allowed for, and no one dreams of getting any more work done in the mill, by any kind of machinery whatever, than can be done by *using the balance of this force to the best advantage*—none, I ought to say, except such ill-informed and misguided, though often very ingenious inventors, who imagine that they can sooner or later contrive not only to make machines, but also to create the force by which to drive them.

"Thus you see," said Lawrence, as he walked along the road with John on his return from the woods, and after making in substance the preceding explanation, "the object of a dam at the foot of a cascade which falls a certain number of feet in a certain distance is to reserve and accumulate the whole of that falling force, so as to take it all at once out at the gate in the dam. Thus the pond formed by the dam is essentially a *reservoir of force*—that is, it is a reservoir of water only for the sake of the potential force that is in it."

"Potential," repeated John. It was the first time he had heard that word in such a connection.

"Yes," rejoined Lawrence. "When the gate is shut and the water in the pond is still, it is not *exercising* any actual force, but it has within it, so to speak, a falling force of ten feet—if that is the height of the dam—which may be called into exercise any moment by opening a passage and allowing it to fall. For every cubic foot of water there would be what is called a *potential* force—that is, a possibility of exercising an actual force of ten foot-pounds depending upon the possibility of allowing it to fall ten feet. This is called potential force, or, more accurately, *potential energy*, for, as has already been said, there are several different meanings to the word force, and the word *energy* denotes this particular kind, and several others that are analogous to it—that is, all that kind of force which can transfer itself from one body to another, and which exhausts itself in one just in proportion as it takes effect upon the other."

"I don't understand it very well," said John.

"No," said Lawrence; "all that you can expect to obtain the first time you consider such a subject as this is a little glimmering of light, which glimmering, however, will grow stronger and stronger every time you think, or read, or hear about it, and at length your ideas will become clear and definite. I can, perhaps, make the glimmering a little brighter now by an example.

THE PILE-DRIVER.

"The case of the pile-driver is as good as any. Suppose the block of iron to weigh five hundred pounds, and that the height to which it is raised by the men at the windlass is twenty feet. Now, to do this, the men will have exerted an energy of ten thousand foot-pounds. This amount is actually spent and gone from their limbs and muscles, and can never be used by them again. It is true that they can raise the weight again, but it will be by new strength, acquired by the digestion of a new portion of food in their systems, or, rather, by the consumption of the results of such digestion. That which carried up the heavy weight is expended and gone from them, and has been transferred to the weight that has been raised twenty feet into the air, where it exists as *potential energy* in the weight, and remains in that condition as long as the weight remains in the air twenty feet from the ground.

"When at length the hammer is let fall," continued Lawrence, "the potential becomes actual energy without any change in the amount of it, or, rather, the potential is converted into actual active energy by degrees *as it descends.* At the instant before it strikes the head of the pile, the whole of the potential energy has been converted into active energy, and at the instant of impact it is nearly all transferred to the pile, heating the head of it in some degree, and driving it bodily into the ground. The energy is not destroyed even then; but we can not follow it any farther now, for what I wish to do is to brighten a little the glimmering of your idea of the peculiar kind of force which is denoted scientifically by the word *energy.*"

"You have brightened it considerably," said John; "but what other kind of force is there?"

"Gravitation is sometimes called a force," said Lawrence—"that is, the action of the earth and the iron upon each other in drawing them together. This action, too, is very properly called a *force*, according to the ordinary use of language. But this force does not *expend itself* in the same way and in the same sense as the force does which is generated in a falling body, or in the limbs and muscles of a man, or that which is developed by the heat of the fire under the boiler of a steam-engine. The *cohesion*, too, by which the particles of a solid are held together is sometimes called a force, but that is not a force in the sense in which the word is used in the case of a falling body or the working of machinery, for this last is a potency which, just so far as it is exerted, is exhausted in one body, and brought into action in another. So, to recognize the distinction, scientific men sometimes designate gravitation, cohesion, and the like, as *properties* of the bodies in which they reside, while the other kind of force is called *energy*, which last also may be of two kinds, or, rather, may exist in two forms, *actual* and *potential*."

John said, after hearing all this, that his glimmering of an idea had become very much brightened by the explanation. Lawrence told him, however, that he must expect to get into confusion again a great many times before his ideas became clear in respect to the subject, even so far as it was at present understood.

By this time they had come back as far as to the mill, where they had rested for a time on their way out to the wood. They stopped a moment at the roadway leading up to the mill, seen on the left of the picture in the last chapter, and stood there a few moments looking at the pond which had been formed by the dam.

"One would say, in looking at it," said Lawrence, "that it was a reservoir of *water;* but it is more strictly a reservoir of *force*—that is, that portion of the falling force which is kept in a potential form by the water being held up to a higher level, and so not allowed to fall; that is to say, is not allowed to convert that portion of potential energy represented by the height of the dam into actual energy, excepting as fast as the mill-men are prepared to use it."

"Thus you see," continued Lawrence, "that a dam may be made to hold back, or, rather, to hold *up* the water of the river for two distinct purposes—that is, it may be for the sake of the water or for the sake of the force. The dam upon the Croton River in New York, for example, is

THE MILL-POND.

for the purpose of retaining the *water*, while that at Lawrence or Lowell is for retaining the *force*. At Lawrence and Lowell they intercept and use the force, and let the water flow away down the stream, except so far as they may wish to take off a small portion of it to use in their houses. At Croton, on the other hand, they intercept the *water*, and let the *force* flow away, except so far as they wish to use a small portion of it to carry the water into the upper stories of houses, or to form jets and fountains in the parks."

Just at this point John moved his head toward Lawrence's ear, and said, in a mysterious, half whispering voice, "Look in that clump of bushes close to the water on the right. There's Rick! He is hiding. He's afraid you will give him a scolding for running away, and I *would* give him one if I were you."

"No, indeed," said Lawrence. And then, pretending not to observe that Rick was trying to hide, he called out in his usual tone of voice, holding up at the same time one of his pieces of wood, "Rick, come here and see our bat sticks, and tell me if you think they will do."

So Rick, finding himself discovered, came somewhat awkwardly out of his hiding-place, and walked toward the place where Lawrence and John were standing. Lawrence showed him the wood, and Rick examined all the pieces with great attention. He thought they would do very well. He then began to apologize for running away, but Lawrence told him it was of no consequence.

"You came with us and helped us find the wood," said he, "and you are entitled to your share of the bats."

"Or, if you like," continued Lawrence, "you can do a little more than your share of the turning, as we did a little more than our share of the cutting."

Rick said that he should like to do that very much, and from that time seemed entirely at his ease. Lawrence made no allusion to his running away except to say, "I see you did not kill the squirrel. I'm sorry, for I would have helped you tan the skin if you had caught him."

Rick said he believed he should have caught him, but he disappeared in a very tall tree. He believed he ran into a hole there. He said, moreover, that he tried to go back to the place where they were cutting the hornbeam, but that he could not find his way. Lawrence said that it was no matter; he could easily make it up by doing a little more work in the turning.

Then they set out again on their walk. Lawrence said he was going to examine John in respect to some principles in respect to force that he had been explaining to him. He was going to examine him, he said, about the philosophy of sliding down hill, or, as he called it, *coasting.*

"But you did not tell me about coasting," said John.

"No," replied Lawrence, "but I explained to you principles that apply to coasting, and, if you understand the principles, you can make a new application of them yourself. Let us suppose that there is a boy with his sled on the top of a hill. How much shall we suppose the boy to weigh?"

"I can tell you what *I* weigh exactly," said Rick, "for I was weighed the other day; it was seventy—something."

Lawrence half smiled at this answer, saying to himself that Rick had a long road to travel in respect to his ideas of exactness before he would be able to appreciate the difference between the lengths of the waves in a red and in a violet ray of light.

"Very well," said he. "Let us suppose that the boy weighs seventy-five pounds and the sled twenty-five; that makes one hundred pounds. Now, how high shall we suppose the hill to be?"

"Half a mile," said Rick, promptly, encouraged by finding that his estimates were received and adopted.

"Yes," said Lawrence, "half a mile; that would be just right for a good slide. Now, suppose there was a church on the level ground at the foot of the hill, and it had a tower fifty feet high, and that the top of the hill was just level with the top of the tower: that would make the hill fifty feet high perpendicular."

Rick looked a little puzzled.

"Or suppose," continued Lawrence, "a well was to be dug at the top of the hill where the boy was beginning to slide, and made so deep that the bottom of it was just level with the bottom of the hill; then the depth of the well, which would show the perpendicular height of the hill, would be fifty feet."

Rick now began to understand what was meant by the perpendicular height of a hill, and Lawrence was going on to explain that as the boy and the sled weighed one hundred pounds, and the height of the hill was fifty feet, the whole force at command for carrying the boy down the hill, and shooting him forward a certain distance on the level ground at the bottom of it, would be the falling force of one hundred pounds descending through a space of fifty feet, which would make exactly five thousand foot-pounds, and this force would all be expended in the friction of the runners on the snow, and the resistance of the air to the passing of the boy and the sled through it. But, finding that Rick began to look a little inattentive, and also, at the same time, coming in sight of a somewhat curiously-built bridge, which was built, in fact, somewhat on the plan of the one shown in this engraving, he determined to change the conversation.

A KING-POST.

"Look at that bridge," said he, "and at the curious kind of railing there is built over it. Let us see which of you will come nearest to guessing what that railing is for."

"It is for a guard to keep the teams from driving off into the water," said Rick.

"No," said John; "those frames are not shaped right for that; they must be for ornament—that is, to put a finish upon the bridge, and make it look better."

"I think that Rick has come rather the nearest," said Lawrence, "for they are for utility rather than for ornament, and his guess was for a kind of utility. They are really to *support the bridge*—that is, they are made to hold up the middle of the beams by hanging the middle portion, as it were, to the two ends. You see the two ends are held up by the stone piers, and the middle is prevented from sagging by the two braces which come together in the middle above, and by a post hanging down from the ridge where they join, and holding up the middle of the beam by an iron strap going round it."

"Ah, yes," said John; "I see it."

"Such a post as this," added Lawrence, "which holds up the middle of a beam by suspending it from two rafters braced against each other above, is called a *king-post*."

If John had been a mere boy, he would have said, "I don't think Rick's guess was any better than mine." But he had by this time attained to manliness of character enough to be willing that Rick should have the credit of making the best guess. He knew very well that giving him this credit would tend to encourage him, and help Lawrence forward in the experiment which he was making upon him.

And so they went home.

CHAPTER VIII.

HEAT.

It must be understood at the outset that the word heat, in its scientific sense, does not relate exclusively to that state of the temperature in any substance which produces the *feeling of heat to the hand*, but to that which causes all differences of temperature whatever. Thus, if a piece of ice is brought in from out of doors when the thermometer is ten degrees below zero, into a cold room where it is only two below freezing, its temperature will be raised from ten below to thirty above zero—that is, it will be raised *forty degrees*. Scientific men say in such a case that the ice has received an *accession of heat*, although to the hand it will still feel intensely cold. In this sense there is no known substance that is entirely destitute of heat. Such a state of things is, however, conceivable. Indeed, the zero of our thermometers was once supposed to mark complete and absolute destitution of heat. It was soon found, however, that that point was not reached by any degree of cold within our experience. The point which in theory corresponds with perfect destitution of heat is called the absolute zero, and many experiments and calculations have been made to determine where it would come in relation to the degrees marked on our thermometers. The result of these calculations, which are too intricate and complicated to be here explained, is that absolute cold—that is, a perfect absence of that quality in bodies which produces the phenomena of heat, would correspond, if it were possible to measure and mark it by a thermometer, with 490° below the zero of Fahrenheit.

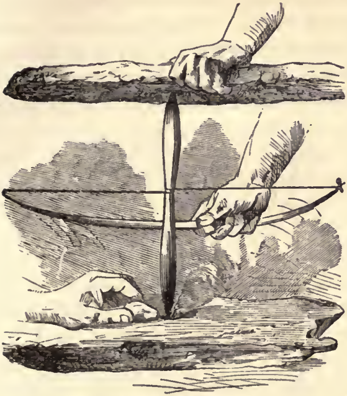
It would, however, not be possible to measure it, or, rather, to denote it by any thermometer. Mercury, which is the substance with which most thermometers are filled, freezes at *forty* below Fahrenheit's zero, and, of course, can not mark any temperature colder than that. Alcohol remains fluid at a much lower point, and is always used in arctic and other regions where the cold goes below the freezing point of mercury. But even alcohol would fail long before the above zero would be reached, for Faraday, by means of a certain chemical process, produced a cold of 220° below Fahrenheit's zero, and at that temperature the alcohol became thickened like a sirup, and would undoubtedly have become solid long before reaching the absolute zero 270° below.

The greatest cold experienced in any part of the United States is about the freezing point of mercury—that is, about forty degrees below the zero of Fahrenheit. In the arctic regions a cold of about eighty degrees has been observed by explorers. At about −220° or −230° alcohol probably freezes, and the utter privation of all heat—that is, the absolute zero—is now generally supposed by scientific men to be at −490°. It is well for the young student to fix these numbers in his mind.

Until within quite recent times the cause of the phenomena of heat has been considered to be a peculiar and very subtle substance which was called *caloric.* It is now, however, universally believed that there is no such specific substance, but that heat is one of the forms which force assumes in the interactions of atoms and molecules upon each other, and the term caloric has gone entirely out of use among scientific men. This interaction is supposed to be of the nature of an intense quivering—or, as one writer calls it, *shivering*—vibration of the particles among each other, though this word shivering seems to be a singular term to apply to heat in any sense. We can not, however, probably depend upon the accuracy, or, rather, the adequacy of any definite notions that we can form of the exact nature and character of an action so far removed from the cognizance of our senses; but there can be no doubt that heat, in all the degrees of it, is really one of the forms which force assumes when it passes from the mechanical movement of masses into the interior substance of which the masses are composed.

Perhaps the most obvious example of this transformation is the case of friction, the mechanical force with which a body is rubbed giving rise to heat in the rubbed substance in proportion as the mechanical force disappears. This effect has, of course, always been known, but it was formerly thought that the mechanical force in some way disturbed and brought out the "caloric," as it was called, which caloric previously existed, in some secret form, in the substance rubbed. That great heat can be produced in this way was known from the earliest times. Indeed, savage nations in all parts of the world have been accustomed to procure fire in this way, though civilized men have found it very difficult to imitate their example. It required, no doubt, some special kinds of wood, having the requisite qualities of hardness and combustibility, which only the savages themselves knew how to find. There are many representations of the manner in which the operation was performed among different tribes. Sometimes they made use of a bow—on the principle described in a former chapter as used in the bow-lathe—for producing rapid rotation.

It is not thought probable that savages could actually set the wood itself on fire by means of any force that they could apply in this way, but only that they could produce



FIRE BY FRICTION.

such a degree of heat that they could inflame by it some kind of very light and decayed wood, or pith perhaps, or some other substance which they had learned to employ as tinder.

And yet it is not uncommon for machinery at the present day—the wheels of cars in a railroad train, for example—to develop so much heat, if the bearing parts are not properly polished, or are not kept thoroughly lubricated, as to inflame the wood that is near them.

Savages always attribute all those phenomena which take place around them, which they can not understand and can not effect themselves, to the agency of spirits, good or bad, and there are many traces among various nations of their entertaining such ideas in connection with the wonderful mysteries of fire, and of their connecting the production of fire in various ways with their religious rites and observances. The following engraving is copied from a sculpture found in Mexico, and evidently gives, in a highly idealized or symbolic form, a representation not only of fire itself, but of the act of a priest in obtaining it by friction while dressed in his sacerdotal vestments, and kneeling, as if the operation was part of a religious ceremony.

HOLY FIRE.

Although many animals show so much intelligence, in certain respects, in counterfeiting the action of men, none seem to be capable of doing any thing with fire. Many of them—as our cats and dogs, for instance—appear greatly to enjoy the comfort, and perhaps even the sense of companionship which a fire affords them, but I believe that no dog ever conceived the idea of bringing even the smallest stick of wood to replenish the fire by which he was lying when he began to feel cold from its going down. There are some dogs that might possibly be taught to do this, but most housekeepers would probably think it would be rather a dangerous accomplishment for such an animal to acquire.

It is said that some races of monkeys are very much attracted by the remains of the fires which travelers sometimes leave glowing upon the ground at their encampments when they go forward on their journey, and that they assemble and gambol around them with great delight; but, though they have sense enough to gather sticks for weapons that they may throw them at their enemies, they never, it seems, conceive the idea of using them as fuel to keep up the fire in the deserted encampment after the party of travelers have gone away and left them in possession of it.

And yet the very lowest savages are familiar with the use of fire, and some writers have formed ingenious speculations on the possible modes by which this wonderful agency may have been first made known to them, before they were advanced enough to produce it themselves by friction. The conceivable modes by which fire may be supposed to have been produced for them by natural means are four, namely: 1st. The accidental collision of one stone with another may possibly, in some very rare combination of circumstances, have set dried grass or leaves on fire; 2d. Lightning, in striking a tree in the woods, may have enkindled a flame; 3d. It is barely possible that one branch of a tree in the forest may have been rubbed against another by the action of the wind in a violent gale, and in a very dry time, with such force as to develop heat enough to produce combustion; and, 4th. The fire may have been furnished by the heat of the molten lava coming down the sides of a volcano into the forests below.

But by whatever accidental mode we may suppose that the primeval man, in emerging from the mere animal, and entering into a more properly human condition, may have first made the discovery of the nature and action of fire, there is no doubt that practically the ordinary method adopted among all savage nations for procuring fire in the primeval ages was the friction of wood; and, curiously enough, after so long a time, and in the highest state of civilization yet attained, we have all returned to the same primitive method. For the universal practice at the present day for procuring fire is by the friction of wood, only we have contrived to envelop the portion of wood subjected to the friction, in order to aid in commencing the process of combustion, with a substance that is more readily inflamed than the dried pith, or fungus, or punk employed by the savages.

Heat being not any specific substance, but only a form which force assumes when it passes from the motion of masses as wholes to that of the atoms and molecules of which the masses are composed, it was to be expected—in accordance with the principle advanced in a previous chapter, namely, that no force can be either increased or diminished in amount, but can only undergo transmutation of form—that the quantity of heat which can be developed by a given amount of mechanical force would be fixed and determinate; and this has been found to be in all cases strictly true. The expenditure of a certain amount of energy will produce a certain definite amount of heat, neither less nor more; and a certain definite amount of heat will do a certain precise amount of work, neither less nor more. By work, however, as the term is used scientifically, is meant not exclusively *useful* effect, but effects of all kinds, including the overcoming the resistance of the air and the friction arising from the imperfection of machinery. This is all *work*, in the scientific sense, that the heat has to do, and it has been found, by a great variety of experiments and observations, made by many different investigators in many different countries, that the quantity of heat and the quantity of mechanical motion which may be converted into each other have a fixed and determinate ratio, from which there is never any possible deviation. This ratio is expressed by a certain formula which denotes what is termed the *mechanical equivalent of heat*, and which every young man interested in the study of science ought to fix in his memory. It is this:

1 unit of heat=772 foot-pounds.

But what is a *unit of heat?* What a foot-pound is has already been explained, namely, that amount of force which is generated by gravitation acting upon one pound during its descent through a space of one foot; and 772 foot-pounds would be the force imparted to a similar body in descending through a space of 772 feet, or a body weighing 772 pounds descending through a space of one foot, or one of any other weight descending through a space in the same inverse proportion.

Some persons are at first inclined to imagine that the force imparted to a body in the lower portions of the space through which it descends is greater than that which is imparted at the commencement of it, from the fact that its motion becomes so much swifter, and the force with which it strikes is so much greater toward the close of its descent. But this increase of velocity and force is due to the *accumulation* of all the different additions of force to it in all the different portions of its descent, and not to any increase in the force imparted to it in the lower portions. There is a very slight difference, it is true, owing to the differing distances of the body from the centre of the earth, but this difference is wholly inappreciable. Practically the amount of force imparted by gravitation is the same for every pound and for every distance within reasonable limits, so that the force represented by a descent of 772 pounds through one foot is the same with that of one pound through 772 feet, and so in all other cases.

But what is a *unit of heat?* In all cases of the measurement of quantities of whatever kind, it is necessary to take some portion of the quantity to be measured as the *unit*, as it is called. Thus the *foot* is a unit of measurement for linear space, and an *hour* for time. The English unit of measurement for heat is the quantity of heat which is necessary to raise the temperature of *one pound of water one degree* of Fahrenheit's thermometer—that is, suppose we have a kettle containing one pound of water; we ascertain its temperature; we then build a fire under it and wait until the water is warmed *one degree*. Now, the quantity of heat which has passed up through the iron of the kettle, and entered into the water, and has been expended in raising the temperature one degree, is taken for the unit of heat.

"I do not see how they can tell precisely how much goes in," said John, one day, when Lawrence was explaining this to him.

"They can not tell exactly in such a case as this," said Lawrence, "for a great deal of the heat made by the fire would pass around by the sides of the kettle up the chimney; and it would be impossible, too, to stop the experiment at the precise instant when the whole of the water would be warmed exactly one degree. Still, that quantity, whatever it is, and however we might attempt to insulate and determine it, is taken as the standard. There are modes, moreover, by which that exact amount may be insulated and made subject to experiment. Such a quantity forms what is called the unit of heat, and it is found that this amount of heat is precisely equivalent to 772 foot-pounds of force—that is to say, the fall of one pound weight through a space of 772 feet, or of 772 pounds through one foot, or of one half of 772 through two feet, will develop exactly one unit of heat*—that is, heat enough to raise the

---

* The manner in which this relation was ascertained by Joule, who was one of the first to determine it, is explained in the volume of this series en-

temperature of one pound of water one degree on its being suddenly stopped by collision with a solid substance.

The young student—and this is, indeed, often the case with many older ones—finds it difficult to picture to his imagination what the nature of the process is by which mechanical force is converted into heat in passing from the mass to the interior constitution of the substance on which the mass impinges. This difficulty can not be entirely overcome, but there are some considerations which carry us a little way in our attempt to gain a comprehension of it; and the first step is to form a clear idea of what is, philosophically, the import of the terms *up* and *down*.

These terms do not, then, as we are apt, without reflection, to suppose, refer to any absolute direction in space, for we all know that on the opposite sides of the earth the absolute directions are reversed. Indeed, the absolute direction indicated by the word downward is different at every different point on the earth's surface.

On the same principle, down, in respect to the sun, is *toward the sun*, on every side—that is, in the *direction of his attraction;* and in the same manner, within the predominating influence of the moon, *down* is in the direction of her gravitation.

Thus the terms up and down, in relation to any centre or point of attraction, denote respectively in *opposition to*, or *coincidence with*, the attraction.

Now there is something in a certain degree analogous to this in the internal constitution of matter—something which might be called the *up and down in chemistry*—that is, there is a certain state or condition of the particles when they are quiescent and in repose, as a heavy body is when it is lying at rest upon the ground; and there is another

---

titled Heat. The formula—1 unit of heat=772 foot-pounds—is called *Joule's equivalent.*

state or condition—which may be produced by the application of a sufficient degree of force—when the particles are not in this condition of repose, but have a strong disposition or tendency to return to it, like the heavy weight above referred to, when raised above the surface of the earth and sustained there, ready, the moment it is released, to return again to the ground with the precise degree of force which was expended in raising it.

Whether these two conditions of the particles of matter depend upon the distance between them—that is, whether the force that is applied is expended in separating the particles from each other, and the force which they afterward generate comes from their tendency to come together again, or whether the effects are due to some other modes and operations of force inconceivable to us, may perhaps be uncertain. The general idea, however, now prevailing, is that the mechanical force which expends itself in friction or collision communicates its motion to the particles of the bodies concerned in such a way as to convert the motion of the mass into that motion of the molecules which constitutes heat, and that this molecular motion has in some mysterious way the effect of separating the particles from each other, or altering their relation to each other in some other respect, so as to leave them somewhat in the condition of the heavy body raised from the surface of the earth, and held there in suspense, with a great tendency to fall; and that, just as when a body so placed is released and allowed to fall, it gives back again in the falling force precisely the same amount of energy that was expended in raising it, so the atoms or molecules of any substance, when their position—or, perhaps, their relation to each other in some other respect—is forcibly altered by the agency, for example, of heat, when they are released from their unnatural condition and allowed to return to their normal arrangement, give out precisely the same amount of heat that was expended in producing the disarrangement, whatever the nature of the disarrangement may be.

Take, for example, the case of water. It is composed of oxygen and hydrogen in a state of intimate and comparatively quiescent union. By applying a certain amount of force, which may be done by means of heat or electricity, and, in fact, in many other ways, this union may be dissolved, and the parts separated from each other. They have, however, an immensely strong tendency to come together again, and re-form the water from which they were derived; but while they continue cold, they are, in some mysterious way, kept from coming together again, just as the weight in the pile-driver is kept from falling by some kind of catch above. However intimately the two gases may be mingled, so long as they remain cool they are kept back from combining; but whenever even the slightest portion of the mixture is heated up to a certain point, the atoms come together with great force—with the same force exactly as that which was expended in separating them—and in the collision, if collision it be, this force, which is extinguished in that form, becomes converted into that peculiar kind of motion which is supposed to constitute heat.

It is the same substantially with all other decompositions and recompositions. A certain amount of force in the form of heat is required to sunder the elementary atoms from each other. This is called the *heat of dissociation*—that is, the heat required for the dissociation of the elementary substances in any compounded body from each other, just as the heat necessary to *melt* a substance is called the *heat of liquefaction*, and that of converting a liquid into a vapor is called the *heat of vaporization*. Thus a certain quantity of heat—that is, a certain number of units—is necessary to convert ice into water. The number of units required for this purpose for every pound of ice is found to be 142; that is, it takes as much heat to convert one pound of ice to water as would suffice to make water that was as cold as ice 142 degrees warmer; and yet the ice, after absorbing all this heat, will only be turned into water, but the water will be as cold to the hand, or to the thermometer, as the ice was before.* Then, when the water comes to the boiling point, it will take in and conceal, as it were, within its substance, about 962 units of heat, while yet the steam thus produced will be no hotter than the water was when it first began to boil.† This amount of 962 units constitutes thus the *heat of vaporization*. Then, finally, when we come to dissociate the oxygen from the hydrogen—that is, to separate the substance of the water itself into its constituent elements, an enormous quantity of heat will be required—not less, as some writers state, than 17,000 units for the pound. This is the *heat of dissociation*.

And now, in reversing the process, when the elements of oxygen and hydrogen are released from the mysterious restraint, whatever the nature of it may be, that holds them

---

* Different observers have come to somewhat different results in determining the number of units of heat expended in the liquefaction, and also in the vaporization of water, though these differences are slight, and are no greater than would naturally be expected from slight and unavoidable differences in the circumstances under which the experiments were made. Sometimes, however, English writers use the notation of the Centigrade thermometer instead of that of Fahrenheit, which makes a great difference in the numerical statement of the results, the heat of liquefaction being in that case represented as about 79 instead of 142, as stated above.

† The number of units of heat absorbed in making steam is often reckoned in round numbers as 1000. Indeed, the quantity is not constant, varying as it does somewhat with the degree of pressure under which the steam is produced, and the consequent temperature at which the change takes place.

apart while they are cold, and allows them to come together again to form the water from which they were derived, they give back the precise amount of force that was expended in separating them. This coming together again, with the great development of force in the form of light and heat which accompanies it, constitutes what we call *combustion*, and the amount of the force thus restored is found equal in heat to the 17,000 units which constituted the heat of dissociation. The two substances now form the vapor of water. And this vapor, in being condensed into liquid water, gives back again the heat which was expended in originally evaporating it—that is, the heat of vaporization, viz., 962 units per pound; or, in other words, that amount of heat *must be abstracted from it;* or, in other words still, it *must be cooled* to that extent to produce condensation. It is now liquid water. If the cooling goes on until it reaches 32° Fahrenheit, when it is ready to begin to freeze, it will give back in the act of freezing—without growing any colder to the hand or to the thermometer while the freezing is going on—the *heat of liquefaction*, namely, 142 units. By saying that it will give out that quantity of heat, it is meant, of course, that that amount must be abstracted from it—that is, it must be cooled to that extent in order to freeze. Thus each step in what may be called the *ascending* process, first to liquefaction, secondly to vaporization, and thirdly to decomposition or dissociation, requires the expenditure of a certain precise amount of force, which, measured in heat, is 142 units per pound for the first step, 962 for the second, and about 17,000 for the third; and on reversing the process, that is, in returning in a *downward* direction, as it were, precisely these amounts, either in heat or its equivalent in some other form of force, will be given out, or must be abstracted, at each of the three grand steps of the descent.

The reader who has given careful attention to the principles explained in this chapter will now be prepared to consider, in the next three chapters, the nature of the solar energy—which is the fountain from which nearly, if not all the movement and action which are witnessed on the earth comes—and to follow this energy in the three principal circuits which it takes in producing the wonderful phenomena which we witness on the globe.

CHAPTER IX.

THE FOUR CIRCUITS OF SOLAR ENERGY.

1. THROUGH THE MEDIUM OF THE AIR.

As was said in the last chapter, the source of nearly all the action of every kind which we see taking place around us on the earth is the radiation from the sun. It requires a careful tracing of the connection of causes and effects to convince us to how great an extent this is true; and there are many examples, both of gentle and of energetic action, taking place on the earth's surface, which it would seem at first was impossible to refer in any way to the agency of the solar rays.

The scene represented in the following engraving, for example, shows the operation of forces, in the one case utterly uncontrollable by human power, and consisting in the onset of waves upon the rocky coast with an energy sufficient to break down and wear away the hardest rocks, and in the other made entirely subject to the will of man, and employed by him in gently wafting his vessel over the stormiest seas. It would not be easy for an uninstructed mind to see how the action of such forces as these could be traced back to the power inherent in the gentle shining of the sun; but we shall see in the course of this chapter that this is really true, and in the following chapters we shall have examples of still more extraordinary transformations.

The solar radiation is known to exist in three forms, and there may perhaps be others that are not known. The three forms are light, heat, and a third class of rays which, though they awaken no sensation in us, are capable of pro-

WORK OF THE SUN.

ducing remarkable chemical effects, and they are consequently called *chemical* rays. They are also sometimes called *actinic* rays, and the kind of energy which they exercise is called *actinism.*

When Lawrence explained this distinctly to John, he advised him to repeat the words *actinic rays* and *actinism* ten times—counting them upon his fingers—in order to make the words familiar to him and impress them upon his memory, and also to establish in his mind the idea of a real and substantial efficiency in what they denote, although this efficiency is not directly perceptible to our senses.

"Suppose," said he, "that you, who can see, were in a country of blind men—"

"The people could not live," said John, "if they were all blind together."

"No," rejoined Lawrence, "I don't suppose that a whole community of blind men could really exist long; so we will suppose that you were a teacher in a blind asylum, and that you were to take your class of scholars out into the sun, and let them feel his rays upon their cheeks as they turned them toward it; they would, of course, be convinced of the existence of one of the forms of solar radiation by the feeling of warmth which they would experience, but they would have no idea of the light—or of the various colors which the rays of light produce—from any sensation of their own. You would have to furnish proof for them of the existence of that portion of the sun's radiation in some other way."

John admitted this, and then Lawrence explained to him that it is somewhat the same with the third kind of radiation—actinism, which produces no direct effect upon our senses of sight or feeling, but which is abundantly proved to exist by certain other effects resulting from it that are of a very marked and striking character.

These three kinds of radiating force, though they are in very close and intimate union as they issue from the sun, and continue thus combined during the whole period of their journey through the immense space which they have to traverse in coming from the sun to the earth, may be separated from each other very easily, and by various methods when they arrive. The possibility of thus separating light and heat, for example, may be shown by a very simple experiment, namely, by interposing a pane of glass, or any portion of a pane, between the hand or the face and a heated stove or a moderate fire. The glass will not intercept any appreciable portion of the light, for the fire or the form of the stove can be seen through it perfectly well, but a very large portion of the heat will be cut off.

There are various other methods by which these different forms of force, as they issue from the sun, can be separated, and each examined and experimented upon by itself.

The solar radiation, then, consisting of these three elements combined, traverses, in the first place, the vast space which separates the sun from the earth—not far from ninety millions of miles—in a mysterious manner, not really well understood; or, at least, the real mode of its transmission has not been positively ascertained, though it is at the present time the prevailing idea among scientific men that all such radiation consists in the communication of a vibratory motion through a peculiarly subtle medium supposed to fill the intervening space, and which has been named *ether.* We have no experience, and, of course, can have no conception of any mode of communicating force except as *transmitted motion*, and to render such a transmission of motion possible through the interplanetary spaces, we have to suppose the existence of an intervening ether, extremely subtle, but capable, through a certain vibratory or undulatory action among its particles, of being the means of the transmission of force.

However this may be, the solar force, in its compound form, makes its way by some means through the intervening space, and on its arrival at the surface of the earth it expends itself and is absorbed chiefly in acting upon four classes of substances which it here encounters, acting in a special and peculiar manner upon each. These four classes are—

1. The Atmosphere.
2. Water in its Liquid and Gaseous States.
3. Water in the form of Ice.
4. The Organs of Animal and Vegetable Life.

The present chapter will be devoted to the consideration of the action of the sun upon the first of these classes—that is, in following out the course of that portion of the solar force which makes its grand circuit through the atmosphere.

The force has to pass through about ninety millions of miles of space without, so far as we know, meeting with any thing to interrupt its passage, or to intercept it in any way except as regards those small portions of it which fall upon the planets and their satellites, and upon our moon; and as these bodies are seldom directly between the sun and the earth, it is very rarely that any portion of the radiation is intercepted which the earth would otherwise receive.

It is, however, only an extremely minute portion of the whole amount which is received by the earth; for, as the solar force is radiated in every direction from the sun, and as, consequently, the rays diverge from each other as they recede, the proportion of the whole which falls upon the earth, or even enters its atmosphere, is exceedingly small.

It has not been ascertained with precision how far above the surface of the earth the atmosphere extends. The *quantity* of the atmosphere is known quite accurately, the whole amount having been ascertained to be such that if the density were uniform, and the same as at the surface of the earth, it would form an aerial sea enveloping the earth to a depth of about five miles and a half. But the density is by no means uniform; for the substance, being exceedingly elastic, the upper portions are greatly expanded, the lower portions being enormously condensed by the weight of all that is above them. Or, to express the same idea in other words, the air becomes greatly expanded as we ascend from the surface, the successive portions swelling into a more and more rarefied condition as the weight of the quantity pressing upon them from above diminishes.

The most accurate observations and calculations which have been made seem to indicate about *forty-five* miles as the height above which the air either ceases to exist, or becomes so extremely attenuated as to produce no perceptible effect upon the radiation entering it.

This height is much less, in proportion to the magnitude of the earth, than most people would be inclined to imagine. On a globe of sixteen inches in diameter the whole forty-five miles would be represented by a covering not thicker than one of the covers of this book.

But, however thin this covering may be in comparison with the size of the earth, the space through which the solar radiation has to pass is very considerable in reference to any of our ordinary terrestrial standards. When we reflect that the loftiest mountains rise to a height of only five or six miles, we must admit that forty-five miles is a very considerable altitude; and as soon as the rays enter the atmosphere at this height, they begin at once to part with some portion of their force. So far as we know, it is force of the heat-producing rays, rather than the light-producing, or the chemical rays, that is first imparted.

And here I must explain some terms which are used in scientific books to express the phenomena connected with the movements of heat and light, and which it is important that the reader should understand. That portion of the heat or light which *passes through* any medium, such as air, water, or glass, is said to be *transmitted.*

That portion, on the other hand, which is turned back from its course, is said to be *reflected.*

That portion which, without being turned back, is bent somewhat out of its direct course, but still goes on, is said to be *refracted.*

And, finally, that portion which is intercepted entirely, and expends itself in effecting changes in the condition of the medium itself, or of substances that it contains, is said to be *absorbed.*

And now for two other important definitions.

Any medium that allows *light* to pass freely through it or from it, without absorbing any portion of it, is said to be *transparent.*

If it does not allow the light to pass, it is said to be *opaque.*

And, on the other hand, any substance which allows *heat* to pass freely through it without being absorbed, that is to say, without detaining any portion of it to effect changes in its own condition, is said to be *diathermant.*

If it does not allow heat to pass through it, it is said to be *opaque to heat.*

When Lawrence explained the meaning of the word diathermant to John and Rick, as he did at one time when they were in the shop with him together, he advised them both to repeat the word ten times, counting upon their fingers. This was his usual custom when he taught young persons any new scientific names, in order to fix them in their memories, and I think it is an excellent practice to be adopted by persons of any age when they meet with any new scientific term.

John, when Lawrence asked him to repeat the word *diathermant* in this way, did not stop when he repeated it ten times, but went on to twenty. As for Rick, he did not repeat it all. He said he did not care much about the word.

Some persons might at first imagine that all those media* which allow of a free passage of *light* through them would also allow the free passage of *heat*, so that the word transparency would answer for both properties. But this is by no means the case, as we have seen in the effect produced by the pane of glass, which allows the light radiated from the stove to pass through it very freely, while it intercepts the heat. Glass will allow heat that is of a very high intensity—such as that from the sun—to pass through it very freely, while it intercepts and absorbs the low degrees.

Experiments have been carefully made upon a great variety of substances, and it is found that the same substances possess the properties of *transparency* and *diathermancy* in very different degrees. Some bodies are both transparent and diathermant. One of the most diathermant bodies known is rock salt, a sheet of it an inch thick intercepting scarcely a perceptible portion of the heat that traverses it; whereas alum, whether in the solid form or as a solution in water, though equally transparent with rock salt—that is, allowing almost the whole of the light which traverses it to pass freely through, intercepts almost the whole of the heat.

Now the atmosphere which surrounds the earth is both transparent and diathermant in a great degree—that is, it allows a very large portion of both the heat and light which enters it from the sun to pass freely through it. It, however, intercepts, or *absorbs*, as the phrase is, a considerable portion of both.

The moment, therefore, that the solar radiation enters the air, a portion of the heat is intercepted and absorbed, and additional portions continue to be absorbed as the rays pass on downward through the increasingly denser por-

---

* The plural of *medium* is *media*, as that of phenomenon is phenomena.

tions of it toward the ground. The three different kinds of rays—that is, those of *heat*, of *light*, and of *actinism*—are all more or less absorbed in this transmission, but the chief effects appreciable by man, that are produced in the action of the sun upon the air, are due to the absorption of the *heat* rays.

The force, then, of heat, whatever may be the actual form or nature of it as it issues from the sun—that is, whether it consists in a vibratory motion in the substance of a subtle ether filling all space, or in some other condition incomprehensible to us—on entering the earth's atmosphere, expends itself in separating forcibly the particles of air from each other—that is, in expanding the air, and so rarefying it and making it lighter, and thus enabling the colder air around to buoy it up by falling by its side, or by flowing underneath it in currents slightly descending. Thus the force from the sun, by making lighter one portion of the air, calls into action the falling force of other portions which have been previously made lighter and lifted in the same way.

This effect, which is comparatively slight in the upper regions of the atmosphere, where the air is very rare and extremely pure, becomes much greater as the rays approach the earth. Here the air itself becomes more dense, and, of course, absorbs more of the heat. Then, in addition to this increasing density, the air near the surface contains a vast amount of foreign substances, consisting of particles of dust raised by the wind—of smoke produced by combustion, and composed, in a great measure, of atoms of carbon too minute to be individually seen, but forming together a haze which has great power to intercept and absorb the heat—and vapors of water, which, even when they are so perfectly pervious to light—in other words, so *transparent* that they can not be seen at all, have still a great power to intercept and absorb the heat. Then, besides the effect of these foreign substances in the air in those portions of it which lie near the surface of the ground, a large portion of the rays which make their way through these obstructions fall, when they reach the ground, upon sandy deserts or arid rocks, and are reflected from them back into the air again, while even those that are actually received into the ground, and expend themselves in warming it, are, to a great extent, radiated again into the air when the ground has become heated by them to a certain degree.

Thus, from all these causes combined, a very large portion of the force which comes to the earth from the sun in the form of heat is expended in *warming, and, consequently, in expanding or rarefying the air*, and producing motions in it, thus affording one of the grandest examples in nature of the conversion of heat into mechanical force.

We might well imagine, at first thought, that so quiet and gentle an influence as the shining of the sun could only result in producing currents of very moderate velocity, which could never lead to the violent commotions and terrible effects which we see sometimes produced by the wind. But the force that is brought into action, though not perceptibly very great in any circumscribed portion of it, becomes vast in its accumulations. For example, when, during the whole of a long summer's day, the rays of the sun pour down upon the Desert of Sahara—a large portion of them being intercepted on the way, and of those that reach the rocks and the sand a large portion being reflected again into the air—the total effect produced over so large an area is enormous. The air, rarefied and lightened, is buoyed up and made to flow over the colder air above; and when we consider that the weight of the air over every *square inch* of surface is, upon an average, not less than *fifteen pounds*, we shall see that the momentum

THE HURRICANE.

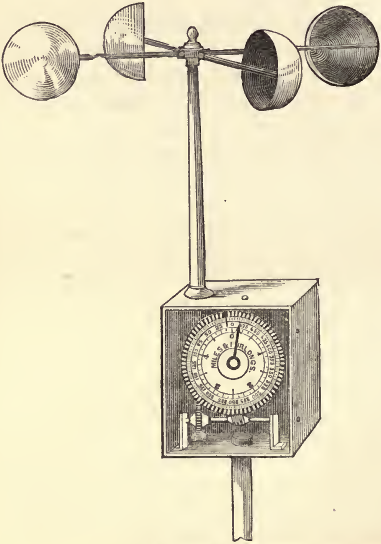
of the mass which will tend to flow in below from the surrounding oceans and continents must be very great. The motion of the inflowing air in such cases is complicated by effects produced by the rotary motion of the earth, of which the air, of course, in the different zones, partakes, and is deflected by the action of it as it passes from one zone to another. At the same time there are other deserts, and other regions of arid rocks, and vast tracts of fields and forests, and great expanses covered with ice and snow, each producing its own characteristic effect in the rarefaction or condensation of the air.

The consequence is, that the atmosphere surrounding the earth, through the effects resulting from its power of absorbing the heat of the sun, is kept in an almost continual turmoil. Currents and counter currents are set in motion above and below, over every continent and every sea, as the air is affected by the constantly changing aspect of the surface of the land, and of the position of the sun, and the condition of the clouds in the sky. In many cases the influences of all these various forces become combined and concentrated, and the action is thus enormously intensified, producing whirlwinds and tornadoes by which houses are demolished, and trees broken through their stems or torn up by the roots.

In other cases the contending forces happen to be so nearly in equilibrium that for a time, and sometimes over a considerable region of land or sea, the air is almost entirely at rest; and it may be, moreover, in such cases, so tempered in respect to its heat, in relation to the warmth of our bodies, that we walk in it amid green fields or gardens blooming with flowers, or along the shore of the sea, and feel nothing but the gentlest and balmiest zephyrs fanning our cheeks—zephyrs so gentle that they scarcely cause the most delicately poised aspen to quiver on its stem.

Even in winter this equilibrium of the vast forces acting upon the air is not unfrequently, for some hours, so complete that the smokes from the chimneys ascend toward the sky without the slightest apparent deflection on any side.

There is something very remarkable about the different velocities of the wind in different places and at different times. The instrument by which the rate of its movement is measured and registered is called an *anemometer*. One of the most usual forms is shown in the engraving.



THE ANEMOMETER.

It is formed of four hemispherical cups placed upon the arms of a horizontal cross in such a manner, as shown in the engraving, that they cause the cross to revolve with a rapidity in some degree proportioned to the velocity of the wind impelling them. The velocity of the rotation is usually about one third that of the wind.

The cross carries with it a vertical axis which is connected with clock-like mechanism below, by means of which the result of any observation may be determined numerically.

For the cross, in being carried round by the wind, carries the clock-work below, which, by means of the endless screw seen under the lower edge of the dial-plate, is made to revolve in correspondence with it, though much more slowly in degree. In order, then, to ascertain the velocity of the wind at any time, the observer has only to observe how large a space on the graduated arc the index passes over in a given time—five minutes, for example. This, when properly corrected for the effect of the mechanism in diminishing the rate of motion, and for the loss of two thirds of the amount in the revolution of the cross, will give approximately the velocity of the wind that has passed the place of observation during the period observed.

This particular instrument, however, is only one of a great number of different contrivances that have been devised for ascertaining the velocity of the wind. This velocity is found to vary from the least perceptible motion—that of a mere "breath of wind"—to the most violent hurricanes, in which the air has a movement of sixty, eighty, and, as has been recently observed on the top of Mount Washington in winter, more than a hundred miles an hour.

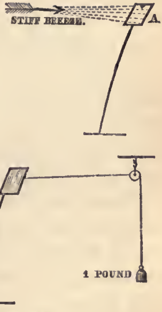
Thus what would be called a gentle, pleasant breeze would perhaps have a velocity of five or six miles an hour. A *stiff breeze*, or rising gale, such as would make it necessary for most ships at sea to begin to take in sail, would be perhaps eighteen or twenty miles an hour, and a velocity of from sixty to eighty miles an hour would form a hurricane. It would be well for young men reading this book to fix these numbers in their mind, so that, when witnessing in their walks winds of different degrees of violence, they may have some approximate idea of the velocity with which the air is moving.

There is another important point in connection with the velocity of the force of the wind on which it is important that every well-informed person should have some tolerably definite ideas, and that is the amount of *pressure* exerted by it upon the surfaces of such substances as come in its way, as the sides of buildings, the stems and branches of trees, the sails of windmills and ships. It is often very necessary for engineers to know this, in order to determine the degree of strength necessary to be given to structures which are to be exposed to the wind, so as to enable them to resist its force. Very careful measurements and calculations have been made to determine the degree of pressure exerted for each different rate of velocity, and the results are recorded in detail in extended tables for the use of scientific men. It is only, however, a few of the results—to serve as specimens—which are important for the general reader, such, for example, as the following, where the second column represents the pressure on each square foot of the resisting surface. This means, in the case of a very stiff breeze, for instance, which gives a pressure of *one pound per square foot*, that the effect of the wind upon one side of a board one foot square, exposed to its action, would be the same as that which would be produced by a weight of *one pound* suspended by a cord, which, after passing over a pulley, was attached to the centre of the other side of the board.

That is to say, that the deflection of such a board, as at

PRESSURE OF TWENTY POUNDS PER FOOT.

A, in the engraving, if supported upon an elastic rod, would be the same as that at B.



PRESSURE OF THE WIND.

TABLE.

Wind.	Pressure.
Pleasant Breeze..........	½ lb. per foot.
Stiff Breeze..............	1 “ “
Gale......................	2 “ “
Hurricane................	20 “ “

To obtain a clear idea of the force represented by the last number in the table, you must imagine yourself holding one end of a rope, which passes over a pulley, and has twenty pounds suspended at the other end, and then conceive of such a force as this acting upon every square foot of the sides of buildings, and of the stems of trees, and of the sails of ships. We can thus help ourselves to obtain some conception of the magnitude of it, and we shall no longer be surprised that trees are bent and broken, that buildings are blown down, and that ships are thrown upon their beam ends and capsized, or are driven irresistibly upon rocks and breakers, as shown in the engraving, which represents a scene at Hatteras Inlet during the war.

Of course, so far as the solar force is transmitted to the trees, and to buildings, and to the sails of ships, and takes effect upon them, it is lost from the air. And there is another mode by which the force is transmitted besides by this direct impingement, and that is by friction. One would not at first suppose that the friction of two such fluids as air and water upon each other would produce any perceptible effect; but a current of air, when driven over the surface of water, instead of flowing smoothly and without disturbance, communicates to it enormous quantities of its force. The commencement of the effect is a rippling of the surface, the little ripples thus produced growing larger and larger as the force of the wind continues to act upon them, until billows of irresistible power are formed, capable of moving the heaviest rocks, and gradually wearing away and destroying—as is shown in the engraving near the commencement of this chapter—the most compact and solid ledges which they encounter on the shore.

The currents of air set in motion by the sun in certain cases of their interaction upon each other produce a rotary or whirling motion, such as we often see, on a small scale, sweeping along the street, and carrying a revolving current of dust and leaves into the air. These phenomena take place sometimes on a very great scale, forming tornadoes on land, exercising sufficient force to sweep into them and bear away trees, houses, and sometimes even men and animals that they meet with in their course. When such whirlwinds are formed at sea, they seize and bring into their vortex the waters of the billows below and the deluge of falling rain descending from the clouds above, and thus form what is called a water-spout.

It is thought to be a very wonderful phenomenon that the motion of two or more currents of wind can result in producing so decided and powerful a whirling motion, and many nice mathematical calculations have been made to show by what precise modes of action such a result can be attained. The same tendency, however, is seen in the currents of water in any rapidly flowing stream, which produce not only boilings and surgings, but also distinct *whirlings* innumerable, whatever may be the precise action of the forces upon each other in producing this result.

And it is wonderful to think, when we look upon so surprising a phenomenon as a water-spout, that a force, issuing, in the first instance, in the form of a radiation from

THE WATER-SPOUT.

the sun, can pass, after its entrance into the air, through such changes in the character and duration of its action that it can finally result in whirling aloft in so marvelous a manner such a mass of water from the rolling and foaming surges of the sea.

The friction of the moving air over the surface of the water produces some other wonderful effects besides its action in the formation of the waves. When the wind continues a long time in one direction, it moves bodily a large mass of water in that direction, forming accumulations which, though relatively to the magnitude of the earth very small, are absolutely, in regard to the quantity of water which they contain, very large; and these accumulations, in flowing away again, aid in forming the remarkable currents which are found constantly flowing in every part of the sea. When such a wind coincides with the action of the tide, the accumulation of water in the harbors upon the coast is sometimes very great, so as to form inundations that often do great damage.

Thus the force derived from the radiation of the sun, and entering the atmosphere as heat, is thence transformed into mechanical motion, which, after passing through many changes, produces a great variety of wonderful phenomena. It takes effect first in forcing apart the particles of air, so far as the force is absorbed by them, and so rarefying it and making it lighter. We must not suppose, however, that in doing this it gives to air any actual *ascending* power, but only that it diminishes its *descending* power, so as to give the greater descending power of the colder air around it an advantage over it, thus enabling this colder air to buoy the warmer air up, for the warmest and lightest air, if unobstructed and unsupported, would fall to the ground as rapidly as a mass of lead.

It is not the lightness of the light air in the balloon which *carries* the balloon up, but the heaviness of the heavier air around it that *buoys* it up; and so the heat of the sun, by warming the air that absorbs this heat, only enables the air that has become cooler to flow beneath it, and so *lift it out of its way.* Thus the heat of the sun, taking the form of force, and forcing apart the particles of air, is the means indirectly of raising it to a position from which, in its *subsequent fall*, after being cooled again, it can produce all the phenomena of winds and storms.

A very considerable part of the force manifested by this inflowing and underflowing of the heavier currents of air is arrested and employed in the service of man. Every boy who flies his kite intercepts and uses a portion of it. Holland employs an enormous amount of it in turning the countless windmills by means of which the country is kept dry, and, up to the present time, nearly the whole of the commerce of the world has been carried on by the force thus derived from the action of the sun. Men are now, however, beginning to make use, on a large scale, of the force lying latent in *coal*, instead of that of the *wind*, for this purpose, though this, as we shall see in future chapters, is, in its origin, none the less than the wind, derived from the radiation of the sun.

In all the cases brought to view in this chapter, though in some of the phenomena described the water is incidentally concerned, the effects are primarily due to the action of the solar force upon the air. In the next chapter we shall have to consider a class of phenomena resulting from the action of the solar influence directly upon the water itself.

CHAPTER X.

THE FOUR CIRCUITS OF SOLAR ENERGY.

2. THROUGH THE MEDIUM OF WATER.

In the last chapter we considered the effects of the energy brought in radiation from the sun in its action upon the air, including some of the effects produced upon bodies of water by the changes thus induced in the condition of the air. In this chapter we have to inquire into the effects produced in and through the element water by the direct action of the solar force upon its substance.

1. *The Expansion of the Substance of the Water in Lakes and Seas.*

This first effect of the solar radiation upon the water is precisely the same in its nature with that which is produced upon the air—that is, it warms and expands the portion which receives and absorbs it, and thus, by lightening it, allows the colder water in the vicinity to flow down beneath it, and cause it to float away over the surface of the colder stratum. There is, however, this remarkable difference in the two cases, namely, that whereas it is upon the *lower* portions of the atmosphere that the sun acts most powerfully, it is upon the upper portions—that is, upon the surface of the water, that they produce the greatest effect. The sun acts upon the lower portions of the air on account of the greater density and the greater *opaqueness to heat* of these lower portions, and also on account of the fact that these portions lie near the surface of the earth where the rays, after once passing through, are *reflected*, and enter it again, thus exerting a double action upon it. In the case of the water, on the other hand, the chief effect is produced upon the upper portions, for the rays have no power to penetrate to any great depth. There is, of course, a great difference in the effects produced by applying the expanding force at the bottom and at the top of any fluid mass, since in the former case the lightened portions have the whole mass to rise through by the buoyancy that is imparted to them, while in the latter it is only a comparatively gentle flow, laterally, over the surface, that is produced by the expansion of the heated part.

And then the air, being a gas, is much more expansible, in proportion to its bulk, by the absorption of a given quantity of heat, than water is. Thus, if a bladder three quarters filled with cold air were to be laid before the hot fire, it might become fully distended by the rarefaction of the gaseous substance within, while, with such a quantity of water within the bladder, the distending effect produced by the expansion that would result from the same amount of heat, though real, and capable, within its proper limits, of exerting a prodigious force, would perhaps be scarcely perceptible in increasing the distention of the bladder.

Through the influence of both these reasons combined, it results that the currents produced by the action of the solar force upon the air are vastly more powerful than those produced in the water. The latter, however, though comparatively smaller, are absolutely, and in reality, enormous in magnitude and extent. The effect of the heat of the sun and of warm winds in heating and expanding the waters of the sea in tropical regions, and also in other regions where the rays of the sun descend upon them in their full force, is to produce currents which have the character and effect of vast rivers in the sea, some of them being many miles wide and thousands of feet in depth, and flowing at the ordinary speed of rivers upon land. The water of the whole ocean is kept in what might be called a perpetual turmoil by the flow and counterflow, the opposings, the combinings, and the collisions of the currents thus formed, consisting in the main, or rather in a great measure, of the colder water from the poles flowing in from below, and floating and bearing away the warmer water above. There are, however, many currents, of enormous magnitude and extent, which are different in their operation and effect from these, being produced by the action of prevailing winds. The force and direction of these is, of course, determined by the force and direction of the winds which cause them.*

2. *Vaporization of Water.*

The effects which have thus far been considered, both in the case of air and water, are due to the expansion of bulk in those substances by the solar energy, without any other change in their condition. But there is another effect produced in the case of water, which consists in a change of form from a liquid to a gaseous state; the air, of course, being already a gas, is not subject to any change in this respect.

It has already been explained in a previous chapter that a very large amount of heat is absorbed and rendered "latent," as the phrase is, in converting water from the liquid to the gaseous form, the amount being about 962 units for every pound of water so changed; that is to say, if a portion of cold water—of the temperature, for example, which it has when just melted from ice, namely, 32°—is placed in a boiler over a fire, then for each unit of heat which each pound of it receives it is raised in temperature

---

* The character and extent of these various ocean currents is more fully explained in the volume of this series entitled WATER AND LAND.

one degree till it acquires the temperature of 212°. This would require, of course, the absorption by the water of 180 units, for each unit raises the temperature one degree, and 180° added to 32° makes 212°.

After this, though the heat continues to enter as fast as ever through the bottom of the boiler, the water is not made any hotter by it, the whole of the heat so entering being employed in some mysterious way in converting the liquid water into a vaporous form; and, what is very wonderful, it requires 962 *units* for every pound of water to effect this change—that is to say, over five times as much heat is expended in converting water at the boiling point into steam, and that without making the substance of it any hotter, as would serve to raise the same water from the ice-cold condition to the boiling point!

The boiling of water by such a process as is described above is the most familiar example we have of the conversion of water into steam—that is, changing it from the liquid to the gaseous form. But substantially the same change is effected in a great variety of other modes. When water "dries up" after being spilled upon the floor, the change that takes place is the vaporization of the water, chiefly by the action of the heat, or, at any rate, through the absorption of heat. This heat may be imparted to it by the beams of the sun, or by the warmth of the fire shining upon it, or else by the heat which it can draw from the surrounding objects. This is the reason of the cooling effect which water drying off from a floor, or a pavement, or from the skin of the face or the hand produces. The process is aided, it is true, by an attraction between the particles of the surrounding air and those of the water in these cases, the water being dissolved, as it were, in the air somewhat as a lump of sugar is dissolved by water in which it is immersed. But the process can not go on any faster than the water is converted into vapor, and this can not be effected without the full complement of heat being derived from some source or other, namely, about 962 units of heat for every pound of water so converted into vapor, though varying somewhat in different cases through the influence of difference of pressure and some other conditions moderately affecting the result.

The point, then, to be specially borne in mind is that a *certain definite portion* of the force comprised in the solar radiation is employed in the vaporization of water upon the earth's surface—namely, that which is equivalent to about 962 units of heat for every pound of water so evaporated; and that this force, combining with the water in the form of heat, is not lost or diminished in the slightest degree, but remains in a *latent* form, that is, entirely concealed from our observation, in the vapor, and that it remains there without any increase or diminution while the water continues in that state; and, finally, when the vapor is condensed into liquid water again, it will deliver up precisely this amount of force, perhaps in the form of heat and perhaps in some other form, but in quantity neither less nor more than that which was originally imparted to it by the sun.

This is one example of what is called by scientific men the *conservation of energy*, which expression denotes the actual permanence and unchangeableness in amount of every portion of force, using the term in the sense of *energy*. The force may change its form, it may for a time pass entirely out of view, its action may be suspended for a time, it may be accumulated and concentrated, and thus increased in tensity, or it may be divided and dispersed, but no increase or diminution can by any possibility be made in its *amount* by the passing of any portion of it out of existence.

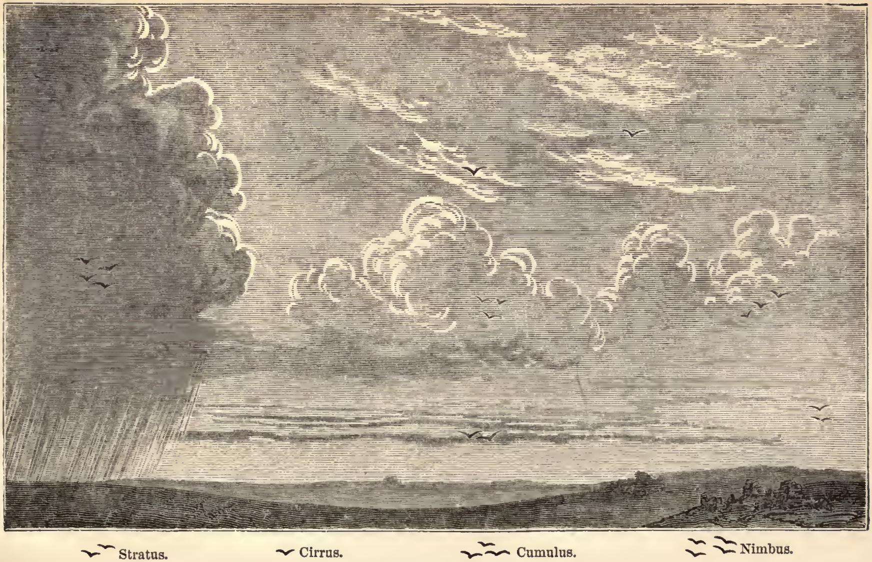
So far, then, as the radiation from the sun falls upon and enters into water upon the earth, whether upon that which forms the surface of the rivers or the sea, the drops of dew upon the grass, the dampness of the ground, or the minute globules of liquid water floating in the air which constitute the substance of mists, fogs, and clouds, the first effect is to expand it in its liquid form, and so make it somewhat more buoyant than it was before, and the next is to convert portions of it into vapor, by a mysterious process, which has the effect of storing in it, in a concealed form, an amount of force equal to that contained in 962 units of heat for every pound of water so converted.

There is another important thing to be observed—a fact which will perhaps surprise the reader if he has never had his attention called to it, and that is, that the vapor, after it is formed, is *precisely as heavy*, that is, that it weighs precisely as much as the water which formed it. We call it light because, bulk for bulk, it is lighter than the air around it, and so is buoyed up and made to ascend. But a pound of water converted into steam produces a pound of steam, which weighs absolutely just as much after its conversion as before, on the principle that a pound of lead is no heavier than a pound of feathers.

The vapor of the water, therefore, produced by the action of the sun, rises into the air, carrying with it the stores of force which it has absorbed from the sun. As it ascends, it acquires from the air around it, which buoys it up, a *falling force* in proportion to the height to which it is raised, which falling force will take effect and come into action as soon as the vapor is condensed into liquid water again, and when thus changed will bring it down in drops of rain. It has also the heat of vaporization—962 units for each pound—which must be abstracted from it by the coolness of the surrounding air in the higher regions of the atmosphere, in the process of being condensed, so as to be formed into liquid water again.

These vapors, being borne aloft by the buoyant force of the heavier air around them, and carrying with them, as it were in store, these two forms of force, become involved in the maze of aerial currents, which, as we have already seen, are continually sweeping through the upper air; and here, as fast as they come in contact with portions of the atmosphere cool enough to abstract the heat stored in the substance of them—that is, 962 units of each pound, return to the liquid state; and inasmuch as the whole mass, as it thus changes its condition, is enormously reduced in size, each several portion, of course, shrinking, as it were, into itself, leaves wide interstices between itself and its neighbors. It is in this way that fogs, mists, and the incipient drops of rain are formed, all of which consist of extremely minute drops of liquid water floating in the air.

The precise manner in which minute globules form and group themselves into masses in the upper regions of the air is affected by a great many other causes, among which, undoubtedly, electricity plays a very important part, in a manner, however, which is yet very little understood. Sometimes a mass of cloud—that is, a mass which consists simply of an aggregation of minute globules of water—will be formed in the midst of a clear and transparent sky without any visible cause, and then, after floating along a little way, will melt away again and disappear. At other times, particularly in a warm summer afternoon, the condensation thus begun goes on with great rapidity; the mass increases in density till it becomes black to our view on account of its intercepting all the light from the sun, which, when the mass of condensed vapor is *thin*, passes through and illuminates it, and the globules increase in magnitude till they fall in a deluge of drops to the earth below. There



CLOUDS: PRIMARY FORMS.

is usually a great development of electric force in these cases, showing itself in the flashes of lightning and the peals of thunder which usually accompany such a shower.

At other times, perhaps, the rising vapors from the earth, after ascending to a certain height, and meeting with no air sufficiently cold to abstract from them the store of heat by means of which the sun has produced them, have spread themselves out horizontally over a wide area, and then a current of much colder air from some cause flows over them and produces a moderate condensation, a broad and thin sheet of haziness is formed, covering the whole sky.

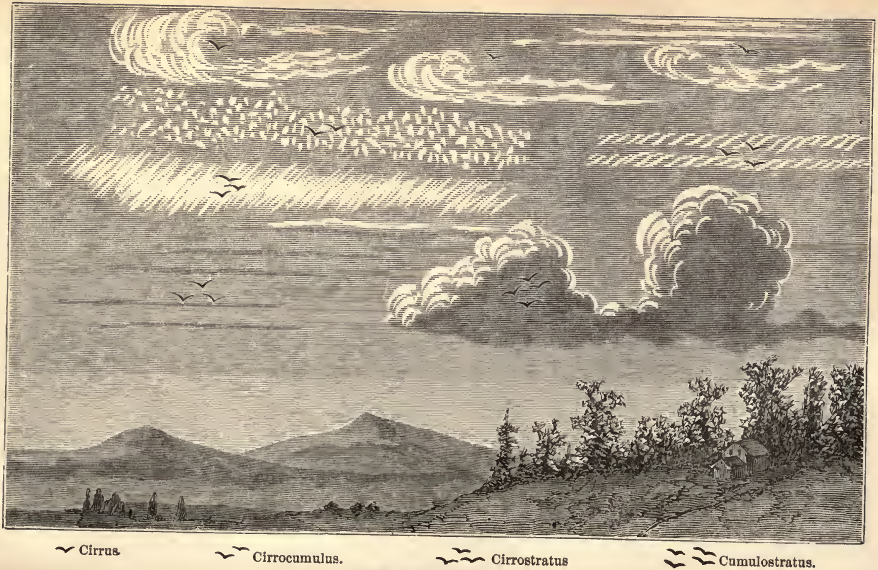
In these and in other ways, through causes that are not well understood, a great variety of cloud formations are produced from time to time in the sky. The principal varieties of these formations have received definite names. The engravings give specimens of the more striking forms, with the names by which they are designated as adopted at the National Signal Office in Washington, and employed in the records kept at the various stations throughout the United States that are under its charge.

The clouds, especially in pleasant weather when the sky is tolerably clear, tend to form in feathery or fleecy masses, designated in the engraving of primary forms by one bird. These are called *cirri*, the singular form of the word being *cirrus*. The second of the primary forms is the *cumulus*, which consists of large rounded masses terminated above by dome-like summits, which, being illuminated by the rays of the sun shining upon the upper portions, have often a brilliantly white appearance, while the lower portions of the mass are dark, being sunk in shadow. Specimens of the *cumuli* are seen in the centre of the picture. As the condensation goes on, the globules of water grow larger, until they fall in copious showers of rain to the ground below, as shown in the representation which is seen at the left hand of the picture, and is marked by the four birds. The cumulus, when advanced to this stage, is called a *nimbus.*

The formation of *cumuli* and *nimbi* goes on most frequently and rapidly in this climate in summer afternoons in the hottest weather. There is something very mysterious and very little understood in the causes of this extremely rapid condensation of masses of vapor in the skies at such a time. The violent electric discharges which accompany the action show that the phenomenon is connected in some way very intimately with the development of the electrical force, but whether as cause or effect it is very difficult to determine.

There is another formation of a totally different kind from these, which consists in a comparatively thin, continuous, and uniform layer, extending over regions many miles in extent—sometimes, indeed, over whole countries, and even over entire continents. We know that they are thin by the amount of light which passes through them, for the under surface is never nearly black, as in the case of the *cumulus;* and that they are of nearly equal thickness throughout from the uniformity of the tint produced by the light that passes through them. These horizontal layers of condensed vapor may, perhaps, be produced by a stratum of air above flowing over one below that is highly charged with moisture, so as to form a continuous condensation of moderate thickness along the whole plane of junction.

However this may be, the fact that such uniform and extended layers of cloud are often formed is very clear, and when they are of moderate extent, so that the whole of one of them can be seen by a spectator at a distance from them, and nearly in the same plane—that is, when the spectator is so placed that the flat cloud can be seen by him edge-



CLOUDS: SECONDARY FORMS.

wise, as it were, it assumes in appearance a long, slender, and needle-like shape, pointed at the ends, as shown by the specimens in the lower part of the engraving of Primary Forms, and marked by the figures of two birds. Such a formation is called a *stratus.**

These three primary forms are combined with each other in various ways, as shown in the engraving of Secondary Forms.

As, for example, in the lower right-hand part of the picture, the *cumulus* is seen blended into the *stratus* below, forming the *cumulostratus*, and in the upper portions the *strati*, and *cirri*, and *cumuli* in various forms are combined, or, rather, clouds are seen partaking of the character of two or more of these formations, constituting what is called a *cirrostrati* and *cirrocumuli.* In some of these cases the vapor is seen forming itself in regular divisions, alternating with portions of transparent air, like a series of waves or mottled patches grouped together with great regularity. Persons accustomed to observe the clouds often remark this peculiarity in the formation of them, and wonder at its cause. It seems plainly to indicate some kind of wave-like or pulsating action in the forces concerned, but the precise character and operation of the cause is by no means well understood.

Now the thing to be specially observed in respect to the formation of clouds, and of drops of rain or flakes of snow

---

* It may be well to remind the young student that there are two words of nearly the same etymological meaning, and both derived from the Latin —one, *stratum*, the plural of which is *strata*, and the other *stratus*, which in the plural becomes *strati*. Both the words originally denoted simply *a spread*, whence they are used in our language to denote a layer of any kind. The two forms of the word have, however, curiously enough, been separated in their use in our language, *stratum* and *strata* being employed to denote layers of earth or rock on the surface of the ground, and *stratus* and *strati* being confined to those of condensed vapor in the sky.

in the atmosphere, and on the knowledge of which the right understanding of this class of the phenomena of nature depend, is that this condensation of the vapors is the mode by which they deliver up and transfer to the air at large the enormous force which they have imbibed *from the sun in the process of vaporization.* We have seen that the amount of this force in the form of heat is 962 *units* to the pound, which is enough to heat four or five pounds of very cold water up to the boiling point. In other words, every pound of water which rises from the river, or the sea, or the ground in vapor, in consequence of the heat of the sun which it absorbs, carries enough heat with it into the air to warm—that is, to make *less cold*—a very large quantity of air, and this heat it *must leave* somewhere in the air before it can be condensed and come down; for it can not be condensed without being cooled, and it can not be cooled without having its heat abstracted from it by the surrounding bodies.

Thus the drying up of water from the ground by the sun is the charging of that water with a large portion of the solar energy, to be wafted into the air and borne by the aerial currents all over the globe, the water to be returned again to the ground in rain after leaving behind it the store of heat with which it has been intrusted. And it can not come back till it has delivered its load, which load, being in the form of heat, is, of course, most easily delivered where the atmosphere around it is cold, and the result is that it spends its force in warming the air, in the sense, that is, of *diminishing the cold* of it in those regions and times in which the air is coldest—in the wintry climates and in wintry seasons, over the summits of mountain chains and in tropical regions, at great height from the ground.

The amount of solar force thus expended upon the surface of lakes, rivers, and seas, and upon the moisture on the ground in vaporizing water and preparing it to be lifted into the air by the downward tendency of the heavier air around it, is enormous beyond all human conception. When we stand upon the bank of a placid lake on a warm summer's day, and observe its aspect as the beams of the sun are lying upon it apparently in so quiet and peaceful a manner, the whole scene suggests to our minds only ideas of inertness or repose. We are little aware of the vast force which the sun is expending in separating the particles of the water from each other and causing them to ascend into the air. In certain lights we sometimes have a glimpse of the *shimmer* produced by the ascending currents of air, but we have very little conception of what this scarcely perceptible movement denotes, nor of the potent agency which the ascending currents of vapor-charged air have to fulfill before the water contained in them is condensed and returned to the earth again.

This process necessarily goes on with the greatest energy in the waters of tropical seas, where the solar radiation exercises its greatest power. The evaporation is here so great that it would soon produce a vast depression in the water through all the region were it not for the continued inflow from the surrounding seas. Millions upon millions of tuns of water are vaporized and raised into the air every day, each pound bearing its charge of 962 units of heat, and each unit representing and being equivalent to a force sufficient to raise one pound 772 feet into the air! The imagination is confounded in attempting to picture to itself the enormity of such a force, and yet nothing can be more certain than the reality of it. That such a force is thus transferred from the rays of the sun to the water of the sea, and that it does produce the effects here ascribed to it, are facts as well established as any truths whatever coming within the domain of human knowledge.

And yet a company of travelers on their voyage to the West Indies, when seated under an awning on the deck of the steamer in a calm, are wholly unconscious of what is going on upon the placid and motionless surface of the water around them. They must have an awning over their heads to protect themselves from the solar force, but they have no idea of the enormous work which that force is performing so silently all around them on the sunny sea.

The heat which is absorbed by the water in being vaporized must be taken from it in some way, as has already been said, before the vapor can be condensed again, and so be allowed to come down. It can be taken from it in the air above in no other way, so far as we know, but by being imparted to some other portions of the air, thus making them warmer—that is to say, *less cold.* They do this to a great extent in the upper regions of the air above the seas where the vapors are formed, and the abundant rains for which the tropics are noted are the result. Other portions deliver their stores of heat to cold air which gathers around the summits of the mountains, and others still are wafted to the northward and southward, where they exert a vast influence in mitigating the intense cold of the frigid zone. It is thus through the medium of watery vapors, conveying stores of solar force from the more heated to the colder regions of the earth, that the great extremes of temperature which would otherwise be experienced in different regions and climes are modified, and a powerful tendency to equalization is the result—a compensating tendency without which some portions of the earth now forming comfortable homes for man would be rendered uninhabitable by the heat, and others by the cold.

The cooling effect of a flowing stream upon the air along its banks, or of a shower falling upon the heated ground, or of the sprinkling of a floor or of a walk, or of dipping the finger in water and then holding it in the air, or even of a drop of water that falls by accident upon the face or hand, is due to this cause, namely, the great quantity of heat that is drawn into the water from the surrounding substances in the process of evaporation, which in all these cases at once begins to take place. Moistening the hand with *oil* does not produce this cooling sensation, for the oil does not evaporate, and so does not draw any more heat from the flesh than just enough to warm the substance of it up to the warmth of the flesh; and if it is as warm as the flesh beforehand, it produces no sensation of coldness at all; but if a drop even of *warm* water falls upon the hand, the sensation of heat which is felt for a moment very quickly disappears, and is succeeded by a sensation of cold, for it almost immediately begins to abstract heat from the hand to enable itself to assume the vaporized form, and so rise into the air.

This principle explains, too, the powerful effect of water in extinguishing fires, the effect being due to the vast quantity of heat abstracted from the burning materials by the water in being converted into vapor by it. If the water acted only by its *coldness* as water, it would produce no more effect upon the fire than so much cold sand; but as the water is instantly converted into vapor the moment that it touches the fire, and as each pound of it abstracts for this purpose 962 units of heat, the fire is soon cooled by it below the point of ignition, or, as we say, is extinguished.

And now we come to another branch of the subject under discussion—that is, to another class of effects produced by the circuit of solar force through the air, which is the *falling force* of the water when it is at last relieved of its charge of heat, and is condensed again, so as to descend in rain; for these two things must be kept distinct in the mind. The heat which each pound of water receives from the solar radiation, and which is expended in converting it into vapor, is one thing; the lifting force which is exerted upon this vapor after it is formed, by the colder air around it, is another. We have already seen what becomes of the *heat*, its destination being to impart itself to the currents of colder air which it encounters in the higher regions of the atmosphere. But after the vapor has thus been relieved of its heat, and has been recondensed into minute globules of water, forming clouds, all the lifting force which was exerted upon it in raising it remains ready to act again in the fall of it, precisely as the force expended in raising the weight of a pile-driver remains in store and in suspense, so to speak, in the raised weight until it is liberated, and then this force comes into action again as the weight comes down.

In the same way, the lifting force by which the enormous quantity of vapor in the atmosphere—millions upon millions of tuns of it—has been raised to the altitude which it often attains, is held in suspense, as it were, till the condensation is carried so far as to set the water free to descend, and then the whole of it is given out again in the falling rain.

The force which a single drop of water exercises in making its way through the resistance of the air, and in finally striking upon the ground, seems very small, but the aggregate of this force in the rainfall of the year throughout the globe is beyond all conception. Some estimate of the amount of water which the atmosphere contains can be made by examining specimens of the air taken from a great number of localities, and even the quantity of the rainfall over extensive regions may be ascertained by observations made in different places within the bounds of the regions to be examined, for it is easy to determine the amount which falls in any one spot by intercepting and measuring a portion of it: this is done by means of an instrument called the pluviameter.

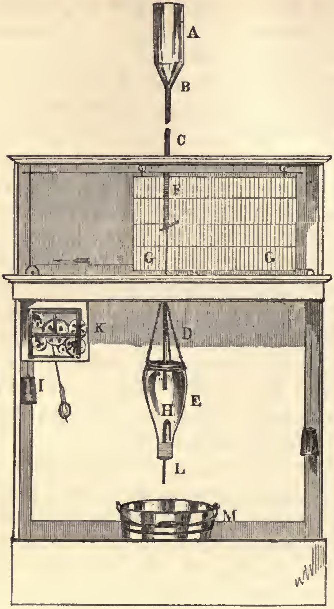
The manner in which the more simple forms of the pluviameter are made and used has been explained in another volume of this series.*

There has been, however, very great improvement in late years in the construction of all instruments for making observations on the phenomena of nature, and most of them now are made *automatic*, as the phrase is—that is, self-acting. In other words, strange as it may seem, the instrument makes the observation and *records the result* without any help from an attendant. Such instruments are called sometimes *self-registering.* The pluviameter, for instance, catches the water falling in rain, measures it, empties the receptacle when it is full, and keeps a record of the result. The manner in which this is done is shown clearly in the engraving on the following page.

In the upper right corner of the apparatus, GG represents a sheet of paper properly ruled and extended over a board, and so mounted that it may be slowly drawn along in an equable manner by means of the weight I, the descent of which is regulated by the clock-work K. The rain is caught in the vessel A, which is placed above the top of the building, and is conveyed by the pipe BC down through the roof to the apparatus DE for measuring it; this pipe, of course, is longer or shorter, as the case requires, as is indicated by the break in it in the engraving between B and C. The apparatus for receiving and measuring the rain, DE, is suspended from a coiled wire, F, which acts as a spring, and allows the vessel E to descend in proportion as it becomes heavy with the water contained in it, and to rise again when the water is drawn off. At the lower end

---

* HEAT, Chapters XI. and XII.



SELF-REGISTERING PLUVIAMETER.

of this spiral spring is a pencil, which is drawn up and down as the vessel E rises and falls, and thus the pressing of the point of the pencil on the moving sheet of paper records all the changes in the position of E which take place.

Now the pipe C from above passes through the spiral wire, and so on downward into the vessel E, carrying down and delivering there the rain which is collected by the receptacle above. Of course, as the vessel becomes heavy from the rain that enters it, the pencil is gradually brought down, and as the paper is all the time moving forward in the direction of the arrow, it traces a line upon the paper *inclining downward to the right*, the degree of inclination being shown by the ruled lines on the paper.

But the most curious part of the apparatus is perhaps the contrivance for emptying the vessel when it has become so heavy with the water which it contains as to bring down the pencil to the bottom of the sheet. This is done by a *siphon*, or bent tube, placed in the lower part of the vessel. The water will not flow out through such a siphon unless the surface of it has risen above the bend. As soon, however, as it does rise to this height, the water begins to flow rapidly through the bend, and continues to flow so until the vessel is emptied; this is done almost instantly, and the empty vessel is then at once drawn up again by the spring. The point of the pencil, in rising, makes a perpendicular mark from below upward, and then, if the rain continues, commences a new record of the progress of it by a new inclined line downward to the right as before.

The sheet of paper is so regulated as to its movement as to be twelve hours in passing the point of the pencil. At the end of that time there is made upon it a perfect record of the rainfall during that period. It is then taken out and filed away, and its place is supplied by a new one. Thus the lines on each sheet preserve a perfect record of the amount of rainfall for twelve hours, the horizontal lines showing the time during which no rain was falling for twelve hours, the vertical lines from below upward showing how often and when the vessel was emptied, and the inclined lines, by means of the rulings of the paper, indicating at what rate the rain fell at every different portion of the interval between them.

This engraving represents the rain-measuring apparatus in use at the observatory in the Central Park at New York. It has been in operation there for two or three years, and by means of the records which it has kept it can at once be known whether or not it was raining, and, if it was raining, at what rate the rain was falling, any moment during the whole of that period.

Records of the amount of the rainfall are kept in a great number of stations at the present day in all parts of the world, though not in many places in so precise and detailed a manner as by the system just described. But the total amount of water which is raised from the earth's surface by the power of the sun, acting directly and indirectly upon it, and then allowed to fall again, is enormous. In the case of the Central Park, for example, the quantity of water, in the form of rain and snow, which falls in one year upon the Park, is sufficient, if it could be retained where it falls, to cover the ground to a uniform depth of about *three and a half feet.* Think of the falling force which would be exercised by such a mass of water as this falling at once from the height of the clouds to the ground! And the total amount of the force is the same, whether it falls in one moment and in a mass, or comes in drops, and the time is extended to a year.

And we can obtain a more vivid idea of the force, too, by supposing it to be a thickness of three and a half feet of solid ice, for ice of the same weight falls no more heavily, in reality, than water. The falling force only takes effect in a different way, the force with which the water strikes being more easily divided and distributed, and the action of it upon the ground being thus less obvious to the senses than that which would be manifested by the same weight in a solid form.

Mr. H. E. Cole, of the United States Signal Service, found that the quantity of water which fell during a single shower in August last upon the city of Boston—an area of about 10,000 acres—from Saturday noon to Monday morning, was about two inches by measure, and amounted in weight to more than *two millions of tuns!* and yet it was by no means an exceptionally copious rain.

He also estimated that the amount of heat set free in the air by the condensation of the vapor from which the drops of rain were derived was equivalent to that which would be produced by the combustion of over a hundred and twenty thousand tons of anthracite coal! All this heat, moreover, is set at liberty in the air, not, it is true, in a concentrated form, as it would be if produced by the burning of that quantity of coal in a furnace, but in the form of that low degree of heat which would appear to our senses only as a diminution of cold, but still in amount the same, and effective in accomplishing equivalent results.

And all this heat would be produced, or, rather, given up by the mere condensation of the vapors from which the water of the shower was derived. There is the falling force of that immense weight of water besides, though this falling force is converted partly into heat, which is expended in diminishing the cold of the strata of air through which it passes in its descent, and partly in producing a similar effect when it strikes the ground. The fall of rain has thus a warming, or, rather, a cold-diminishing tendency. This tendency is often very perceptible in the winter, the formation and descent of rain, or even of snow, being usually accompanied by a diminution of the intensity of the cold. In a hot summer's day the effect is disguised by the rapid evaporation of the water as it reaches the warm ground, which causes it suddenly to absorb so great a quantity of heat again that the effect at the surface is a cooling one. The case is somewhat analogous to that above described of a drop of warm water upon the hand.

It is only a small part of the falling force, however, with which the rain is charged, that is expended when it strikes the ground, for it has yet usually a great descent to make before it reaches its final level at the sea. In Boston, it is true, this remaining portion of the descent is small, the distance being but a few feet; but in the interior of the coun-

EXPENDITURE OF FALLING FORCE.

try, and especially in mountainous regions, the water has often a descent of many thousands of feet yet to make, and goes on expending the remaining portion of its falling force as it flows on in wearing away the bank of its channels, or in falling with great momentum over lofty precipices, or tumbling over a rocky bed, and forming long cascades.

When men have work to be done in which this portion of the falling force of the rain can be profitably employed, they intercept it in its passage by dams, and draw off the force, so to speak, to their mills, where they employ it in driving their saws, working their looms, or turning their spindles, as shown more fully in a preceding chapter. And so manageable in their hands this force is, and so practicable is it for them to divide and direct it, and to appropriate it to the purposes they require, that, by means of the right arrangement of machines, it can be made to manufacture a pin complete, taking the wire from the coil, straightening it, cutting off the right length, fashioning the head, sharpening the point, and entirely finishing it, without any help at all from the workman, who has only to stand by and watch the process as it goes on. Every thing is done simply by the falling force which the sun has stored in the water in raising it from the sea into the air.

It is, however, but a small part of the force exerted by the falling water from the atmosphere that is utilized by man. It is true that there are tens of thousands of mills, and pumping-engines, and factories driven by it in different parts of the earth, but then there are hundreds of thousands of streams which go tumbling down the mountain sides, and making their impetuous way along ravines and valleys, expending an enormous amount of force in modes wholly independent of the action of man.

CHAPTER XI.

THE FOUR CIRCUITS OF SOLAR ENERGY.

3. THROUGH ICE FORMATIONS.

ICE is only one of the forms of water, and, scientifically speaking, the action of solar force in its connection with the formation and dissolution of ice on the surface of the globe might properly have been treated in the last chapter. But the nature of this action, or, rather, the effects produced by it, are so striking and peculiar, that they deserve to be treated under a separate head.

We have seen in the last chapter that all the force in the form of heat which comes from the sun, and enters the air and water upon the earth's surface, is there expended in producing a variety of motions, consisting of breezes, storms and tempests in the air, and vast currents in the sea, and in raising immense weights of water to the sky, and letting them fall again with great force to the earth; and the question at once arises, What ultimately becomes of all the force thus developed? On the principle heretofore laid down that no force can ever be lost, Where does this force go? or, rather, What becomes of it in the end? Unless it is disposed of in some way, it would accumulate from year to year, and from century to century, in receiving continued accessions from the sun, and would end in making great and permanent changes in the condition of things on the globe.

But no such change takes place—that is, no great and perceptible change. The year rolls on; the seasons follow each other in regular rotation; the heat and cold undergo fluctuations, it is true, to a certain extent, from time to time, but the fluctuations are confined within comparatively narrow limits; the course of change returns into itself again in due time, and every thing goes on substantially as before. Since, then, force can only *change its form*, but can by no means pass out of existence, what becomes in the end of the inconceivably enormous quantity of it which falls in the form of heat every day of every year upon the surface of the earth from the sun?

We leave out of the question at present that portion of the solar radiation which consists of *light* and of *actinic force*, and consider only that of heat, which is the only portion of the solar radiation with which we have thus far been dealing.

The answer to the question is, that this heat, after passing through various transformations and producing a vast variety of phenomena, and taking many different forms, is finally, as it can find opportunity when the influence of the sun is withdrawn, *radiated away again* beyond the earth's atmosphere into the vast regions of space that surround the earth.

That is to say, in the daytime and in the summer the sun pours into the earth floods of heat. In the night and in winter this heat—substantially the whole of it—after passing through many changes of form, producing, when turned into mechanical force, currents in the water, and winds upon the land, carrying down and bearing away vast quantities of material from the mountains and the plains, undermining and grinding down the rocks along the shores of the sea, and driving mills and machinery in vast numbers for the benefit of man—goes off into space again, where it disappears from our view. What finally becomes of it is at present an unfathomable mystery. The closest scrutiny of science has not yet been able to follow it into that vast store-house of cosmical force which is formed by the interstellar regions, or to discover with any definite certainty the processes by which it is ultimately again concentrated into suns.

There will be something more, however, to be said on this point in another chapter.

The water, then, that exists on and near the surface of the globe, exists in three forms, according to the quantity of heat which it has absorbed from the sun. In its lowest condition in respect to heat, it is ice. It is reduced to this condition whenever it has radiated into space—either directly of itself, or indirectly through other substances—enough heat to reduce it to 32°, and also afterward a quantity of heat equal to 142 units per pound, this being the "heat of liquefaction," so called. It is this 142 units per pound that maintains the water in a liquid state while it continues liquid; and all water that is liquid contains this amount of heat in what is called a latent condition, employing it in some mysterious way in maintaining the liquidity.

Now the water which is in the polar regions, and also in the temperate regions during the winter when the sun is away, is at liberty to radiate its heat into space very freely, especially at night, when there are no clouds in the sky to form a curtain to intercept the rays. The water, therefore, in immense quantities, in all these regions, loses its heat of liquefaction and becomes solid. Wherever the radiation is impeded by clouds, or whenever the water is made warm—in the sense of being less cold—by friction, as in the case of running streams, or of cataracts falling over rocks, or of billows surging over the sea or being dashed against the shore, the process of refrigeration is hindered. But where the sky is clear, and the water is calm and still, and the sun is away—that is to say, in a clear cold night in the winter, and even in the daytime when the sun is low in the horizon, so that the radiation from the sun to the earth is partially or wholly suspended, while that from the earth into space can go on—then the water loses gradually its heat of liquefaction and becomes solid.

And this is the philosophy of the formation of ice in the high latitudes.

This process, however, does not go on in any uniform or continuous manner, but fitfully and with great fluctuations. Throughout vast portions of those parts of the earth's sur-

CONTENDING RADIATIONS.

face a constant contest is going on between the radiation from the earth, abstracting heat from the terrestrial waters, and that from the sun counteracting the loss. The character of this conflict is well illustrated in the engraving representing a scene in Spitzbergen, where the sun has very little power, the radiation of heat *from the earth* tending to condense the vapors in the air, and to solidify the water on the sea. But the feeble radiation of the sun maintains an unequal and doubtful contest with it, yet so far prevails, at the time and under the circumstances represented in the engraving, as to prevent such an amount of condensation in the vapor as would produce copious rain, and to limit the formation of ice upon the surface of the sea.

Far to the north or south, in the arctic and antarctic regions, the influence of the sun is so feeble, especially through the winter portion of the year, that the heat radiated and lost in space during the cold season is not replaced during the summer, and the ice *accumulates.* All the vapors in the atmosphere which find their way thither, after having been raised from the sea in more genial climes, lose their heat, both of vaporization and liquefaction, and are condensed in the air into snow. Or, if the radiation of the stored heat is more slow, so that the moisture falls in rain, it loses its heat of liquefaction as soon as it comes in contact with the intensely cold surfaces that receives it—that is, it freezes as it falls—and forms with the snow that has previously fallen beds of ice of great thickness and solidity; and as there is very little melting of the mass during the summer, the depth of the accumulation increases from age to age, until glaciers are formed hundreds and sometimes thousands of feet in thickness.

Here it would remain, increasing in depth indefinitely, were it not for one most extraordinary action to which such accumulations of ice are subject, and that is, that, however gentle the incline of the surface on which they lie, they are subject to a slow creeping motion down the slope toward the sea. And, what is still more wonderful, even when such a glacier fills a tortuous valley bordered by steep and ragged rocks on each side, the enormous friction of the sides is not sufficient to hold it. It moves slowly onward in summer and in winter, by night and by day, at the rate of a few inches in twenty-four hours—the rate varying, however, with the temperature and other circumstances—until at length it reaches the shore of the sea.

The movement of such glaciers has been studied more in Switzerland than in any other country, and a long time elapsed, and many exact observations were made, before mankind could be satisfied that masses of such apparent solidity, and so firmly held in their rocky beds, could really move. But the proof soon became overwhelming. In Switzerland the glaciers generally lie in vast ravines and valleys among the mountains, and they gradually work their way down to the warmer valleys below, where the ice at the terminus is melted by the sun. But in Greenland and in other polar regions such formations of ice cover extended tracts of country like a vast bed of rock, and move slowly down till they reach the sea. Then and there the margin, crowded onward by the mass behind, protrudes over the water, till immense masses of it are broken off and floated away. And this is the origin of the icebergs floating in the sea, which so often attract the attention of voyagers in crossing the Atlantic.

Besides these mountains of ice, formed upon the land and floated off by the waves, vast sheets of solidified water are formed in certain seasons over the surface of the sea, while the sun is away, and in places where the water is not kept warm—that is, kept from giving up the large quantity of heat which must be abstracted from it to bring it from a liquid to a solid state—by the incessant turmoil of the waves. Ice thus formed is called *field ice.* It is sometimes from six to ten feet in thickness, and often vast tracts of it become detached from the shores of the sheltered waters where it is formed, and are floated away by the currents or driven by the winds out to the open sea, to be finally broken to pieces by the agitation of the waves.

FIELD ICE.

The remains of the icebergs and the fragments of the field ice are borne by the currents sometimes a thousand miles or more from the places of their origin. It is often a matter of surprise to the voyagers that encounter them that they melt so slowly and endure so long, just as people who do not reflect upon the subject are often surprised that a piece of ice should be so slow in melting in a glass of water in a summer's day. The *glass* of another tumbler, forming a mass much greater than the lump of ice, is warmed in a few minutes when tepid water is poured into it, while the ice in a similar quantity of water of the same temperature parts with its cold—that is, is affected by the surrounding heat—very slowly, for portions of it remain in the condition of ice for a long time.

The reason is, that the glass employs, so to speak, all the heat which it receives in simply *warming itself.* It uses none of it to change its internal constitution from the solid to the liquid form. Every unit of heat which the water passes into the glass warms it at the rate of one degree per pound. But in regard to the *ice* the case is different. The large quantity of 142 *units* of heat per pound must be employed in melting the ice; that is to say, this great amount must pass into a latent condition, and so disappear from observation, in the work of liquefying the ice, before any of it will be employed in warming the liquid that results. This is the reason why the ice melts so slowly, and why, consequently, icebergs and fields of ice endure so long into the summer in the comparatively warm waters of the mid-Atlantic, and why a lump of ice will keep the water cooler in a tumbler so much longer than a cold stone, as large and as cold as itself, would keep it.

We have now to consider a very striking and important difference which results in the effects produced by a portion of the heat of the sun which is employed in liquefying ice from that which expends its energy in vaporizing water.

The difference is this, that whereas, when water is changed from the liquid to the vaporous form, it *goes up*, while, on the other hand, when it is changed from the solid to the liquid form by the same agency, it sends the resulting currents down.

Thus the vapors produced by the heat of the sun ascend and float over the surrounding air. The water from a floating iceberg sinks and flows away underneath the other water at the bottom of the sea.

The reason is that water, in freezing, swells, so that a mass of ice is lighter than the water out of which it was formed. Warm water, too, is lighter than cold water, for it is only just before it freezes, and while it is freezing, that it swells. Before that time it swells as it becomes warm, and diminishes in bulk as it grows cold. Thus, if we have water only in a sea, or in a tumbler, or in a receptacle of any kind, the warmest portion of it will tend to be at the top, and the coldest of it within certain limits at the bottom—that is, so long as there is none cold enough to *be ready to begin to freeze.* As soon as any portion of it approaches the freezing point, it rises to the surface and freezes there, and after it is frozen it remains upon the surface until it is melted again. Then, and only then, it goes down.

The icebergs, as has already been said, are formed generally on the land in Greenland and Spitzbergen, and in other arctic and antarctic countries. They are formed by the gradual accumulation and consolidation of the snows over a great extent of country, the whole formation working slowly all the time onward toward the sea; and as the immense mass reaches the sea, and portions of it are broken off and borne away by the floating power of the water, they, of course, are lighter than the water, and keep at the top, where the warmth of the water lies. Thus, in a sea covered more or less with floating ice, we have the *coldest* —that is, the ice—and also the *warmest*—that is, the water which has been moderated in temperature by the sun—upon the top, while the coldest liquid water lies motionless, or flows in a slow current in the depths below.

And as fast as the ice is melted by the sun, or by the warmth which it absorbs from the surrounding water, a mass of cold water results, both from the liquefaction of its own substance, and also from its cooling effect upon the liquid lying around it. This cold water descends continually, as fast as it is produced, in vertical currents, until it reaches the level, in the vast underflow, where the temperature and the density corresponds with its own.

It is true, the process is in some degree complicated, and that the direct results are modified by the *saltness* of the sea; for salt water is heavier than fresh, on account of the weight of the salt which it contains; consequently, a body of fresh water, even though somewhat colder than the salt water in which it was lying, might float upon or near the surface of it. It is also true that, for some mysterious reason, when ice, on losing its heat of liquefaction, becomes water at 32°, it is not quite at its maximum density. Its maximum density is at about 40°. It follows, from the operation of both these causes combined, that if an iceberg could be simply melted, and if the water resulting from it could be kept distinct from the sea water around it, it would form a floating mass to remain on the surface. But, in fact, the water thus produced soon becomes so mingled with the sea water that it acquires from it a portion of its saltness, and also of its cold—that is, it absorbs from it so much heat that the compound mass becomes heavier than the water of the surrounding sea, and, as fast as it thus becomes heavier, it goes down. Thus, while the vapors produced by heat from liquid water *go up*, the liquid produced in the same way from solid water *goes down*.

The result is that, as a general truth, there is a stratum of comparatively warm water flowing in a thousand currents over the surface of the sea, and a vast bed of colder water moving slowly in a contrary direction far below, the general tendency of the warm water being from the warm regions of the earth toward the colder ones, and of the cold water from the colder regions to the warmest ones; these general movements, however, being modified, and changed, and disturbed in a thousand ways by the action of the winds, the formation of eddies, the trend of coasts, and a multitude of other disturbing causes.

If ever, then, the reader crosses the Atlantic, and looks out from the deck of his vessel to a sea covered in part with icebergs and ice floes, he must picture to his imagination, first, a vast general movement of the surface water toward the north; secondly, an equal movement toward the south of an immense body of colder water in the depth below; and, thirdly, a countless number of vertical streams from every iceberg and floe, formed by the cold water resulting from the melting of the ice, flowing *downward*, hundreds of fathoms, from the upper currents to the under one.

The general rule of the flow of the warm water on the surface toward the poles, and of cold water from the poles toward the equator, is subject, as has already been said, to a great many modifications and exceptions, arising from the action of local causes. The northward flow, for example, of the warm water in the Atlantic Ocean is greatly intensified within certain limits, forming what is called the Gulf Stream, and, on the other hand, within certain other limits, commencing in Baffin's Bay, and so coming down on the eastern coast of North America, something like a vast eddy is formed, and the set of the surface water, though cold and full of icebergs and floes, is toward the south. The result is, that an immense quantity of floating ice is brought down from the extreme northern regions by the currents, and carried around the northeastern coast of Newfoundland, and thus drifted out into the middle of the Atlantic, where it encounters the northern flow of the warmer water, and is rapidly melted. The encounter of this quantity of ice and ice-cold water with the warmer waters from the south results in a condensation of the vapors in the air so great and so extended as to cover the surface of the sea, and envelop all the coasts, in certain seasons of the year, with fogs, and mists, and scudding clouds, and driving rain, which make the navigation fearful to the mariner.

Thus, to sum up the whole process in one word, the radiation of the terrestrial heat *from* the earth, in the vicinity of the poles, deprives the water there of its heat of liquefaction, and forms vast quantities of ice, which, as long as the masses are held in place, remain unchanged from age to age; but, as soon as they become detached from their places and are set at liberty, they come at once under the control of winds and currents, and, though the general set of the surface currents is toward the pole in all these waters, a vast number of the liberated masses are brought under the influence of counter currents and of winds, which bring them down, after many stops and much floating to and fro, to warmer climes.

They greatly assist in this way in equalizing the temperature of the earth, or, rather, in promoting a tendency to equalization in it. Icebergs and ice floes, by the very process of their formation, must tend to make the polar regions that produce them less cold than they otherwise would be; for ice can not be formed without having the heat of liquefaction taken out of the water from which it is formed, and there is no way by which this heat can be taken out except by the surrounding bodies, or the surrounding space, receiving it. And then, by their dissolution, they must make the tropical regions less warm; for they can only be dissolved by *absorbing* heat to supply that which was lost in the freezing, and the heat thus required the surrounding objects, or the surrounding space, must render, and must cool themselves somewhat in doing it.

It is thus, by the processes described in this and the preceding chapter, that a large portion of the solar force which consists of heat is distributed through the medium of water, in its different forms, very extensively over the surface of the globe. It is received from the sun in its greatest intensity in the tropical regions, and in a constantly diminishing ratio from those regions to the poles. As we observe its progress, we see it pursuing its devious and meandering way through the atmosphere and over the sea, moving in its course through a thousand changes, forming currents and counter currents, and eddies innumerable; sometimes advancing through the ocean in a majestic stream, and at others receding in an equally vast reflex, revolving in whirlpools and tornadoes, beaten back from rocky coasts, rising in vapors, and descending in snow, hail, and rain, but still, on the whole, gradually making progress from the equatorial toward the polar regions, and also stealing off continually by the way, until, in the end, it has all escaped from the earth by radiating into the regions of infinite space, where we can follow it no farther; the last portions of it, taking their departure from the earth at the polar regions, and leaving behind them icebergs and ice floes to be sent back for new supplies.

For the icebergs may be considered in some sense as empty *vehicles of transportation*, going back to be charged anew with supplies of heat, which are to be brought from the tropics to the poles. In being formed into ice, the water which composes them gave out, as we have seen, its supply of heat, especially the 142 units per pound which had before maintained them in the condition of liquidity. As they move south they voraciously seek to recover this supply. They seize it from any of the water that they meet which is able to supply them. When they thus become liquid again, they join the other streams of cold water flowing, in the main, toward the south, and sooner or later

EFFECTS OF THE AVALANCHE.

they become warm enough to take their turn in flowing north again as warm and liquid water on the surface of the sea, or to be raised as vapor into the air, and to be wafted by the winds where the heat that they have now recovered again is most required.

A very considerable portion of the heat which finds its way in these channels of circulation takes effect, as mechanical force, in forming currents, and driving icebergs and fields of ice to and fro with enormous momentum. The ice acts, in fact, not merely by the grinding effect of great floating masses driven by the winds into the bays and against the rocks of the coast, but also by the slow but immensely powerful action of the glaciers in valleys of the interior. Ice also acts sometimes in another very striking manner by forming a solid covering on the sides of a mountain or hill, and afterward, by its fall in avalanches, carrying away portions of the declivity with it.

In this way it gradually increases the precipitousness of the mountain sides, and in the end forms rugged and barren peaks of extraordinary picturesqueness and grandeur.

When this action of the ice takes place on the sea-shore, so that it is conjoined with the undermining and abrading influence of the waves, the result is greatly to modify the configuration of the coast and the character of the scenery; and, inasmuch as the land every where throughout the globe is subject to great alterations of level, and to great changes in respect to heat in different seasons, and in different ages of the world, it is often difficult to determine, in respect to any scenery which presents wild, broken, and rugged features to the view, whether the agency of ice may or may not have been employed in some former periods in producing the forms which now characterize it so strongly.

Notwithstanding the intense cold which prevails in the

SCENERY ON THE COAST OF NORWAY.

arctic and antarctic regions, and the violent action, so incessant and so destructive, of the various ice formations, such as the glaciers on the land, and the floating icefields and icebergs on the sea, there is, perhaps, no region on the earth more profuse in the productions of organic life. Low forms of vegetable and animal existence swarm in the seas. These favor the growth and propagation of innumerable shoals of fishes and other marine animals that are enabled to bear the cold by being endowed with an organization that is satisfied with maintaining in their bodies a temperature only slightly, if at all, elevated above that of the water in which they swim. A higher order of animals, requiring a higher temperature to keep their organs in play, multiply upon and around the icy shores by feeding upon the fishes—whales, seals, and walruses in the sea, gulls and other birds of prey, in countless millions, in the air, and bears, foxes, and reindeer upon the ice. These all, requiring, as they do, for their high organization, a supply of warm blood in their veins, are provided both with the means within of rapidly developing heat from their food, and also of preserving what they thus evolve by means of a special provision in each class—feathers for the birds,

AMONG THE ICEBERGS AFTER SEALS AND WHALES.

furs for the land animals, and thick coats of blubber and oil for those that find their home in the sea.

And, finally, as these different grades of animals prey upon each other in regular succession, the elements of sustenance passing up from the lowest to the highest as the exigencies of each rank require, man comes in at last to prey upon the highest of them, these elements having then taken the form adapted to his use. It is the feathers, the furs, and the oil, as means of protection for him from cold and darkness, which draw him to the spot. He comes in search mainly of the seals and the whales, for the sake of the light and the warmth which he can procure for himself from the constituents of their clothing.

Perhaps, however, the most wonderful fact connected with the world of vital activity to be witnessed in these regions is, that all the force that is manifested in it, like that which is exercised by the waves and currents of the sea, the fall of water on the land, the crashing impetus of fields and mountains of ice, and the violence of hurricanes and tornadoes, is derived solely, though more or less directly, from the radiation of the sun.

And this brings us to the subject of the next chapter, which is to treat of the fourth circuit of solar energy, namely, the course it follows, and the effects which it produces by its action in and through the organs of vegetable and animal life.

CHAPTER XII.

THE FOUR CIRCUITS OF SOLAR ENERGY.

4. THROUGH THE ORGANS OF VEGETABLE AND ANIMAL LIFE.

There are many very curious analogies to be observed in comparing the phenomena of vegetable and animal life, both in respect to structure and function, especially in the lower forms of the organizations that we observe. Indeed, in these lower forms the two principles seem almost to blend into one, and it has been found difficult to draw precisely the line of demarkation which separates them. In their relation to *force*, however, the distinction between plants and animals seems broad and clear. In fact, in this respect they are antithetical and complementary to each other; for

It is essentially the function of vegetable life to *collect*, *absorb*, and *store* the energy that comes from the sun, and that of the animal organization to *appropriate and expend* it.

It is true there is a great deal of expenditure of force to be observed in connection with the vegetable organization, but it is all incidental, and there may be also more or less of the direct absorption of solar energy by the animal organization, but this, too, is incidental. The *primary* object of the organs of the one is to absorb the force to be derived from the solar radiation, and that of the other to receive the force so made ready for it, and to expend it, and thus set it free again.

In the lower forms of animal and vegetable life these two functions may possibly be found, it is true, to be united in the same organization; but in all the higher forms, and even in the lower, so far as they have yet been fully observed, the distinction is clear.

Thus the grass in the field collects the radiant solar energy, stores it in its leaves, its stems, its flowers, and especially in its seeds. The ox receives it thus prepared for him, and expends it in plowing fields, and drawing loads, and exercising and expending mechanical force in other ways, for his own benefit or for that of man.

The flower-bearing plants of the field are busy during the long summer mornings in laying up force from the sun in their juices. The insect comes and receives the stores of force thus prepared, and expends a portion of it in his motions to and fro, whether of creeping, of leaping, or of flight, in his combats with his enemies or his prey, and in the industrial labor which he employs in excavating his hole, or building his nest, or spinning his web or cocoon. In some cases, as in that of the bee, he stores away a portion of this for future use in the form—or, rather, in the chemical constitution—of certain substances which he produces, such as wax and honey; and this reserved supply is afterward appropriated and brought into action either by himself, when he uses it for food at a later period, or by the bear or the man who plunders his hive.

What we have to consider in this chapter is the manner in which the solar force is thus absorbed and concentrated in plants, and afterward appropriated and expended by animals; in other words, to consider the fourth branch of the subject of solar energy, namely, its circuit through the organs of vegetable and animal life.

The apparatus by means of which the appropriation and the storage of solar force are secured in plants is

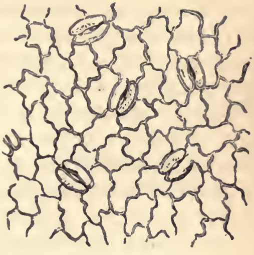


Fig. 1.—STOMATA.

found by the microscope to be wonderfully complicated and curious. All over the surface of the leaves are found small openings, called *stomata*, from the Grk. word *stoma*, meaning a mouth. These openings lead to "intercellular cavities in the subjacent tissue," into which the carbonic acid gas and the aqueous vapor of the atmosphere are received; and here, in some way or other, the solar force takes effect in separating them into their elements of carbon and hydrogen on the one hand, and oxygen on the other. The carbon and hydrogen the plant reserves and builds into its tissues, while it sets the oxygen free. The elements, thus separated from each by the overpowering force of the sun, retain their immensely strong affinity for each other, and this affinity is ready at all times to come into action again whenever the conditions favorable for such reunion shall be attained.

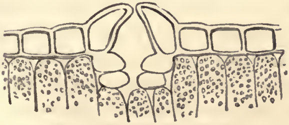


Fig. 2.—SECTION OF A STOMA.

In Fig. 2 we have a sectional view of a *stoma*, showing its connections with the interior tissue. The *stomata* are altogether too minute, in most plants, to be seen by the naked eye.

We have already seen in a former chapter that when a weight is raised above the surface of the earth, the force which is expended in raising it is, in a certain sense, stored in it, and retained until the weight is released, and that then, in coming down, it exercises precisely that degree of force in its descent, neither less nor more, which was expended in raising it; and that the force so liberated may be applied to any purpose for which man may wish to apply it, and must necessarily be expended in producing some effect or other.

Now it seems that there is an *up* and a *down*—or something strikingly analogous to this—in the chemical constitution of bodies—that is to say, that a certain change may be produced in the relation of the particles to each other by the application of force — as in the case above described, of carbon and hydrogen on the one hand, and oxygen on the other—which is such that when they are released from the constraint, and certain other conditions favor, they tend to restore themselves to the former state; and what is most remarkable, and most important to be understood and remembered is, that in thus restoring themselves, they give back, in returning to their former condition, precisely the same amount of force as that which was expended in producing the original change; and, moreover, that this force, thus released, may be applied to any purpose for which man may wish to use it, and *must* be expended in producing some effect or other.

There is still a great deal of mystery about the precise nature of the changes which take place in the internal constitution of matter, which correspond in their effects to the raising and letting fall of weights in relation to gravitation. Some scientific men suppose that this up and down movement, so to speak, in chemistry, is very closely analogous in its nature to that of raising and letting fall a weight—that is to say, that the sun, in acting upon compound substances in plants, in some mysterious way separates the elements to a certain distance from each other, and, still more mysteriously, places them in such a condition in relation to each other that they are kept apart, until finally they are released from this coercion, and that then they come together again with prodigious force. This falling together, as these philosophers imagine it, is precisely analogous in its nature to the coming together of the earth and the iron weight of the pile-driver when the weight is released from the lifters which hold it, only, of course, the distance through which the force acts is inconceivably minute in one case in comparison with the other.

To show clearly what is meant by this, we can take the case of water. Water is composed of the two substances oxygen and hydrogen. In the form of water the two elements are intimately united, and are held together with enormous force. There are various ways, however, by which this force can be overcome and the elements separated. The separation may be effected by the force of very great heat, or by that of electricity, or by the superior attraction for one of the substances of a third substance brought into action upon it. In some form or other, however, very great force is necessary to separate these elements from their combination with each other in water; and, moreover, after they are once separated, they have an extremely strong tendency to come together again, and, in coming together, to develop and redeliver, as it were, the same force that was expended in separating them. Still, this tendency to reunite is suspended and disguised while the two elements remain *cold*, just as the tendency of the pile-driving weight to fall is suspended and disguised so long as it is held by the grapple above.

A child who should know nothing about the construction and action of a pile-driver might look at one standing on the bank of a river, with the weight raised, and have no idea of the force stored in it and held in suspense by the brown mass of iron near the top of the guides; and when this mass is suddenly released by a slight movement of the workman below, he is astonished, and perhaps alarmed, at the sudden and violent descent of it, and at the tremendous force with which it strikes upon the head of the pile.

In the same manner, any one might see the two elements of oxygen and hydrogen brought into their gaseous form in their separation from each other, and, not knowing by what mysterious means they are held apart, would never imagine what an immense force is held in suspense by the condition in which they are placed in relation to each other; and when, at last, they are released from this distention, as they may be by raising the temperature of the smallest portion of them up to a certain point, we are astonished at the suddenness and violence of the force with which they rush into union again.

This force, in all such cases, shows itself, in the first instance, in the form of heat; and this is the reason why it is only necessary to raise a minute portion of the mixture to the temperature necessary for releasing them in order to release the whole; for the heat developed by the union of the first set of particles affected raises the adjoining sets on every side to the right temperature for union, and these the next, and so on with amazing rapidity through the entire mass—the solar force which had been stored in them by the separation being brought again into action by their union with such suddenness and rapidity as to produce, under certain circumstances, a violent explosion.

In other cases, as in the burning of wood, for example, or the reunion of the separated elements in the bodies of animals, the process is more slow. The reason is, that while, in the case of two gases mingled together, the particles of the substances which tend to unite are in close juxtaposition to each other, in the case of solids, one of the substances is in a compact mass, and the other has no access to the interior portion any faster than the outer por-

SOLAR FORCE RESTORED.

tions are consumed and borne away. The chief substances which are separated from each other in vegetable growth are carbon and hydrogen from oxygen, and it is chiefly of carbon and hydrogen, in various forms and proportions, and in various modes of combination, that wood and nearly all other vegetable products are composed. Consequently, when wood is set on fire, or, to speak scientifically, when a portion of the wood is raised to such a temperature that the carbon and hydrogen can again be seized by the oxygen of the atmosphere, the process of reunion can go on only so fast as the outer layers of the wood are wasted away, so as to afford access for the oxygen to the interior portions. Thus, though the "falling together," as it is now generally considered, of the oxygen and the carbon, and the oxygen and the hydrogen, gives out all the force, either as heat or in some other form, which was expended by the sun in separating them, the process of reunion, even in the greatest forest conflagrations, proceeds in a regular and gradual, though sometimes very rapid manner.

If there was enough oxygen at hand to supply at once all the carbon and hydrogen contained in the woods shown to be on fire in the engraving, the whole forest would flash into a flame in an instant with an inconceivably violent explosion, sufficient not only to blow the horse and wagon to atoms, but to shake the whole country around with the force of the concussion.

In the case of the animal organization, the liberation of the force stored in the food is so regulated, if the organs are in a healthy condition, as to supply heat and mechanical force just so fast as it is needed for maintaining the life and the movements of the animal; for the food which the animal takes consists simply of substances containing heat and force from the sun, stored in them by the processes of vegetation, and brought into such a condition as to be easily received and assimilated by the animal organs.

In consequence of the form in which the solar force is thus stored, and the wonderful adaptation of the vital organs to the work of receiving and developing it, it is liberated within the body of the animal very gradually, as it is needed, and often large portions of it are retained and are not liberated at all, so that when one animal feeds upon the flesh of another, the stored force is transferred in an unexpended condition from one organization to the other. Thus the insect receives its food—that is, its supply of stored force—from the juices of the plants in which a portion of the solar energy has been laid up by the processes of vegetation. The insect expends a portion of this force in his creepings, or his leapings, or through his wings, but retains a large portion of it in the tissues of his body unexpended. The swallow, in devouring many insects, transfers the energy to his own system, and expends large portions of it in giving the prodigious impulse to his wings necessary for his rapid and tireless flight; he does not, however, expend all that he receives, but large portions of it are stored in his flesh, to be transferred to the body of the hawk or the eagle when the swallow is in his turn devoured.

In the same manner, the ox, in a double sense, supplies force for the use of man; he receives the solar energy that is stored up in the blades of grass into his system; a part of this energy he expends directly in drawing the loads or plowing the fields of man, and a part he stores in his muscles and in his flesh, which form the beef that man uses for food. In this way the force is transferred in an unexpended form to the human system, and man proceeds to expend it in spading or hoeing the ground, or perhaps in guiding the labors of the successor of the ox that furnished him with his supply. Thus it is the solar force, in process of

CONTENDING CURRENTS OF SOLAR ENERGY. VICTORY EASY.

being stored, that forms the grass of the field. It is the same solar force, after it is thus stored and has been transferred to the body of the ox, that impels the plow; and it is the same—that is, a portion of the same, after a double transfer—that is exercised by the higher organs of man in superintending and directing the whole operation.

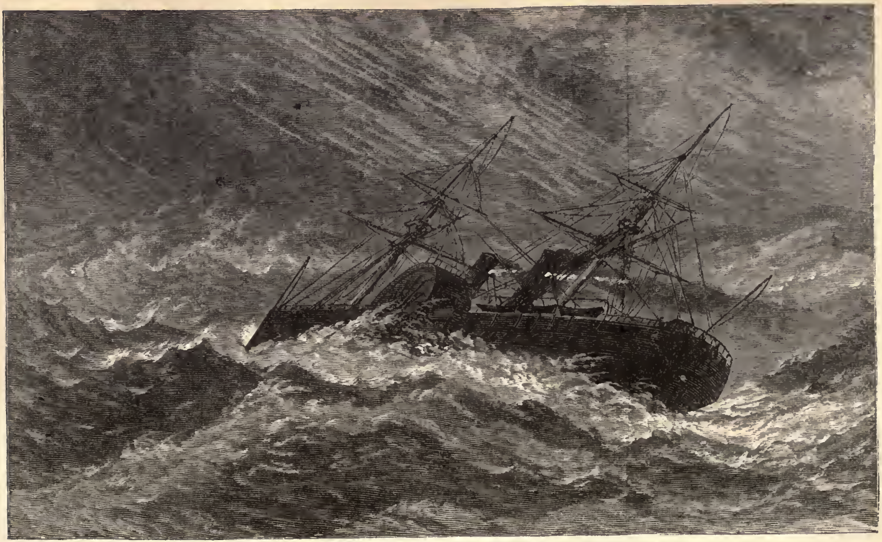
Thus, in its circuit through the organs of vegetable and animal life, the solar force is brought by slow degrees into action in the animal system, in proportion as it is required, for the various purposes of life. It may be brought into action also in the same gradual manner without passing into any animal organization, for the carbon and hydrogen may be made to recombine with oxygen, and thus deliver out the force which the sun exercised in separating them in a great many other ways.

The currents of solar energy, in the different circuits which they pursue, may and often do come into opposition and conflict the one against the other. We have innumerable examples of this in the ordinary phenomena of nature as witnessed around us. A very familiar example of it is afforded in the spectacle of a steamer ascending a river against the current by the force derived from the combustion, under the boiler, of wood taken from the bank of the stream, as is shown in the engraving, and is seen every day on the Mississippi River.

The flow of the stream is produced, as was shown in the preceding chapter, by the falling force of water raised into the air by the solar radiation—that is, by that portion of the solar energy that performs its circuit through the water and the air. The force by which the engine of the steamer is driven is derived from the wood which grew upon the bank; for the *steam* is in no sense, as is often supposed, the *source* of the impelling power, but only the *vehicle* of it. In other words, the force which carries the steamer against the current is the force set *free by the combustion of the wood*—that is, by the reunion, with great eagerness, of elements separated from each other by the same amount of solar energy acting through the organs of vegetable life. The two forces shown in action in the engraving, one acting upon the water, and through it upon the bottom of the vessel, and tending to carry the vessel down the stream, and the other that of the revolving paddles driven by the action of the heat through the intervention of the steam, meet and oppose each other, and the strongest carries the day.

In this case the contest is quite a gentle one, and the victory is gained with very little manifestation of violence on either side; but in other cases the struggle is often a fearful one, and the victory for a long time doubtful. The next engraving represents the struggle between the force evolved from coal and that of the sun acting through the air and water in the winds and waves, which is often exemplified in the passage of a French or English steamer in crossing the Atlantic.

The scientific student must cease to regard the steam in these cases as in any sense the source of the power. It is only the vehicle by which the force is conveyed; for the true source, as has already been said, is the coal. It is common to speak in popular language of the power of steam, but the power of steam is only a power of the kind that is exerted by one end of a pole when a man is pushing at the other end—that is, it is in all cases *power imparted to it*, and *transmitted through it.* When the fires go out under the boiler, the power of the steam comes to an end. All its boasted energy ceases at once, and it becomes as inert, and as helpless, and as incapable of carrying on any work by itself as the cranks, or piston-rods, or any other lifeless part of the machinery.



VICTORY DOUBTFUL.

Nor is the coal itself any more an *original* source of the power by which the machinery is worked. It is the source only in the sense of being the substance in which the force is stored, ready to be called into action by the will of man. The real source, and the original one, so far as we can at present trace it, is the sun.

That is to say, as was explained in the last chapter, the sun, by its action upon the organs of vegetation in the leaves of plants, separates the carbon and hydrogen from their natural combinations, and fixes them mysteriously in some new combinations, without, however, at all diminishing the great strength of their tendency to come together again; but, for some reason not understood, this tendency can only come into action very slowly under ordinary temperatures, though it bursts into great intensity of action when the temperature is raised above a certain point, provided the oxygen with which the carbon and hydrogen wish to unite is at hand. If, however, the carbon and hydrogen are kept beyond the reach of oxygen, they have, of course, no opportunity to reunite, and the store of reserved force will remain unexpended for an indefinite period.

This happens when the wood, or any other vegetable product, is kept under water, for then there is no oxygen accessible to combine with the imprisoned elements. It is true that the water itself contains a large supply of oxygen, but it is oxygen which is not free. It is already combined with its full proportion of hydrogen, and can take no more. Wood, therefore, that is kept immersed under water will retain its reserved force for an indefinite period.

Now it happens that there are various ways by which large quantities of wood and other products of vegetation are accumulated in vast masses, which are submerged in water and preserved, and in the end become beds of coal.

These beds of coal, of course, contain enormous stores of solar energy, which were deposited in the substance of them years ago, when they were formed. The traces of the ancient vegetable origin of the beds are found very abundantly in the structure of the coal when examined by the microscope and by other means.

There are various natural processes by which such deposits of vegetable matter are now being formed.

One is by the "rafts," so called, formed by the floating trees which accumulate at or near the mouths of certain great rivers flowing through countries covered with forests. Immense quantities of this stored force are carried down every year by the Mississippi, and by the great rivers of Asia, until they reach the mouths of them, or the flat land near the mouths, where they become matted together in vast masses which float upon the surface of the water, or, being sunk by the weight of the roots and of the earth adhering to them, become water-logged, and form the foundation of shoals, or even, in process of time, of islands.

In other cases aquatic plants have grown up from the bottoms of shallow lakes, spreading their leaves over the surface of the water until the mud at the bottom is so filled in every part by the ramifications of the roots, that, in the end, the whole stratum in which they grow is made buoyant with them, and it rises to the surface, and covers the water with a floating field, as it were, on which, in time, mosses and lichens, and at last shrubs and bushes grow. The lake is thus transformed into a bog, the soil and the vegetation growing upon it being supported, in a somewhat unstable and fluctuating condition, by the water below. As the thickness of this layer increases by earthy matter brought upon it by the wind, and by the decay of the vegetation which gathers upon it, the whole mass gradually subsides, until at length, in the course of ages, the whole basin of the lake may be filled with vegetable matter submerged in water and so preserved, thus holding the enormous store of solar force of which it is the custodian for the use perhaps of man in future, and often very distant ages.

There is another mode still in which vast accumulations of vegetable matter are at the present day in the process of formation on the earth's surface, and that is by the slow growth and accumulation of peat in bogs. If this formation takes place in a tract which is slowly subsiding, the peat may form to a great thickness in the course of ages, and the vegetable material so accumulating may be preserved by the constant infiltration of water as the ground subsides, or even without subsidence by an increase of the deposit over an extensive area.

In all these cases the tract in which these vegetable deposits are formed may subsequently subside, and be covered by strata of sand or gravel washed over them. If the subsidence goes on, new depressions may be formed and new deposits of vegetable matter produced above the others, and be separated from them by strata of sand, or gravel, or clay hardened into strata of rock. Processes precisely analogous to these are now slowly going on in various parts of the earth, and there is abundant reason for believing that in former ages they went on on a vastly more extended scale than we witness at present, and the immense beds of coal alternating with strata of slate and sandstone formations which now constitute the "coal-measures," so called, of England and America, as well as of various other portions of the earth, may have thus been formed.

The quantity of reserved force thus stored among the strata beneath the surface of the ground, and the extent to which they are annually drawn upon for the purposes of man, are enormous.

Great Britain, it is estimated, brings out of the earth from her mines about 20,000,000 tuns of coal annually, and the stored force which she thus brings into action is equal to that which would be realized from the labor of about 133,000,000 of men, which is probably ten or twenty times, and perhaps fifty times the force of all the laboring men in the kingdom. This is one secret of the immense power to which England has attained. With only perhaps five million of laborers to feed and clothe, she enables these laborers, by means of the stored solar force in the coal, to do the work of more than a *hundred and thirty* millions. By means of the human energy thus re-enforced, she manufactures iron, and lays down railroads, and builds ships, and spins and weaves for half the world.

The question of the amount of coal accessible to man contained in the geological formations of any country depends not only upon the extent laterally of the coal-bearing strata, but upon the *depth* to which they can be worked. And, singularly enough, the question of depth does not depend upon the difficulty of raising the weight through so great a distance, inasmuch as the coal itself; or, rather, the force that is stored in it, does that—that is to say, the force developed by the combustion of a part of the coal serves to raise the other part, with all its store of force retained in it, up to the surface, whatever the depth may be. The real difficulty which puts a limit to the possible depth of these excavations is the heat; for the heat is found to increase regularly, and so rapidly that at the depth of four thousand feet the temperature of the mine, through that of the rocks which it traverses at that depth, becomes about 105°, and it is not possible for laborers to continue to work with the surrounding air at a higher temperature than that, even with all the relief which can be obtained by the best known means of ventilation.

So that the question for any country, in respect to its store of reserved force, is to determine how long the supply of coal will last that is contained in all the strata underneath it down to the depth of four thousand feet.

Many different calculations have been made within a few years past to determine how long the supply of coal buried in the bowels of the earth in England will last, and the results vary enormously—from a few hundred to many thousand years. A commission of scientific men recently appointed to examine this question came to the conclusion that at the present rate of consumption the supply would last about thirteen hundred years; but with a consumption increasing in the future at the rate at which it has been increasing for a few years past, the supply would be exhausted in about two hundred and eighty years. Other estimates have been made, however, which give much longer periods than these.

The stores of coal held in reserve by the strata that underlie the continent of America are vastly greater even than those of England; they are, indeed, practically incalculable. It is only a very small beginning that has yet been made in bringing into use the immense supplies of stored force thus held in reserve for the present and future generations.

There is something very interesting and curious in the principles which govern the redevelopment of the force held in reserve by combustible substances; for a combustible substance is, in principle, one the particles of which have been separated by the sun from those of some other substance toward which they have an immensely powerful tendency of attraction. This tendency, inconceivably great as it is, takes effect through distances so minute that we can not directly perceive the action of it; we can only observe its effects; and combustion is simply the reunion of these separated elements under favorable conditions by which the force with which they combine is fully developed, and manifests itself in the evolution of intense light and heat.

If the substance is a *gas*, the light and heat developed take the form of *flame;* if a *solid*, the light and heat liberated give it the form of *burning coals.*

The chief substances which are thus separated from each other, to combine again afterward with the evolution of light and heat, are hydrogen and carbon on the one hand, and oxygen on the other. It is found by careful experiments that the amount of heat, or, rather, of force in the form of heat which is developed by the combustion—that is, by the reunion of the oxygen with the hydrogen and carbon—is generally in proportion to the amount of oxygen so recombined; and consequently, as the elements above named, and others not so common, as in that of sulphur, for example, demand different quantities of oxygen to satisfy their different appetites, the heat furnished by the combustion of them is very different in the different cases, the combustion of hydrogen giving the greatest heat, that of carbon coming next, and that of sulphur least.

Thus the force stored in different kinds of fuel varies in a considerable degree with the different proportions in which they contain the above elementary substances in their composition, and the quantity of heat—that is, of force in the form of heat—has been carefully ascertained. Some of the principal amounts are given in the following table. In order fully to appreciate the values expressed in the last column, the reader must remember that a unit of heat is the quantity required to raise a pound of water from its condition when just melted from ice *one degree of Fahrenheit's thermometer.* To raise it, consequently, from the freezing to the boiling point—that is, from 32° to 212°, would require about 180 units of heat for each pound.*

And each of such units of heat is equivalent, as has already been shown, to 772 foot-pounds—that is, it represents a force sufficient to raise a pound weight 772 feet into the air, or that which would be developed by the fall of a pound weight through that distance.

The following table, then, shows the number of units of heat developed by the combustion of the several substances named in it. The letters in the second column denote the words carbon, hydrogen, and sulphur:

TABLE.†

Substance.	Composed of.	Units of Heat.
Hydrogen	H.	56,000
Petroleum	C. and H.	22,000
Spermaceti	C. and H.	18,000
Charcoal	C.	14,500
Anthracite Coal	C.	14,000
Sulphur	S.	3,500

These figures denote, of course, the total amount of force which is stored in these several substances, or, rather, in their condition in relation to the oxygen which surrounds them, and which is actually brought into action when the

---

* Not exactly, however, since it is found that the quantity required to produce an increase of one degree in the temperature varies slightly as the temperature increases. The amount also is very different for different substances; that, however, which is required for water at a temperature of 32° is made the standard of measurement.

† In such tables as these, the numbers given can, of course, only be considered as approximations to the truth, since, in ascertaining values so extremely difficult of precise determination, different experimenters will, of course, reach somewhat different results. The young student in science will also find in different books tables differing at the first view very decidedly from each other, owing to the fact that some use the degrees of Fahrenheit's thermometer, and others those of the Centigrade in designating units of heat.

oxygen reunites with them. It is only a small part of this total amount that can be really utilized—that is, made to serve a useful purpose by any of the contrivances of man. It is calculated that only from one twentieth to one tenth of the amount of force stored in coal can be made effective for useful work in the best constructed steam-engines that have hitherto been employed, though a London firm, it is said, have recently made improvements by which they claim that one *fifth* of the whole amount can be utilized. Even at this rate far the largest portion is wasted, and a wide field is open for future engineers and inventors in devising arrangements for greatly increasing the benefit which generations to come may derive from the store of energy which nature has laid up in the beds of peat and coal for their use.

Still, notwithstanding the imperfection of the appliances by means of which this stored force is used, the saving of human strength by the employment of it is immense. The stones used in the construction of the great pyramid of Egypt have been calculated to weigh, in all, about 12,000 millions of tons, and it required the labor, it is said, of 100,000 men for twenty years to raise them and put them in place. Dr. Lardner calculated that the force developed by the combustion of 480 tons of coal would have been sufficient to do the same work.

And yet Great Britain employs for her various purposes the force contained in 20 *millions* of tons every year.

It will assist the student to fix the principles above explained in his mind, and to enlarge his conception of the extent to which all the manifestations of physical energy which he sees around him are effects derived ultimately from the radiation of the sun, if he should analyze some of these phenomena as he observes them, and trace back the

THE SUN GIVING HELP.

chain of causes that produce them to their origin in the sun. The results he will find in some cases quite curious.

Take, for example, the case of the light-house upon a rock at sea. The light in the lantern comes from the combustion of oil, this combustion consisting simply in the liberation, in the form of light and heat, of the force stored in the oil. This oil was elaborated in the body of the whale from substances containing stores of force which served the whale as food; and these, if traced back to their origin, came from the agency of the sun in separating the carbon and the hydrogen from the oxygen in some vegetable organization, or some organization on the confines of the vegetable and animal world, which fulfilled the ordinary functions of vegetation. In this forcible separation of these elements, a portion of the solar energy was absorbed and stored. Thus the light that beams from the lantern of the light-house is a light which may be traced back by a circuitous route, and through various forms and disguises, to the sun.

In the same manner, though by a very different path, the force by which the winds and the waves are impelled comes, as we have already seen, from the agency of the solar beams. Thus the solar force, coming by one path and reappearing in one form, sends help to the mariner to aid him in making his way through the perils with which the same force in another form environs him. In other words, the force which the sun stores in the oil is used to guard against the mischief which might flow from that which he stores in the water and in the air.

And even in cases where the force which comes through one circuit can not be made actually to help, it may be employed to give warning.

This is shown in the engraving of what is called a bell-buoy, which consists of a floating structure bearing a low open tower or cage, within which is suspended a bell, which is rocked and swung incessantly by the motion of the sea, without the aid of any human attendant. These buoys are mainly useful in fogs, whether occurring by day or night, in either of which cases a light-house would be useless. Now the fog, as we have already seen, is produced by solar agencies acting through the water and air, and the motion of the waves, and the consequent rocking of the buoy and ringing of the bell, are the results of the same energy acting in a different portion of the same great circuit. In this case, accordingly, the sun, in one division of the same circuit, applies his energy in giving warning and information to man to save him from dangers which he creates by his action in another division.

Only one of the most simple of the forms in which the solar energy takes effect in the processes of vegetation, namely, the separation of carbon and hydrogen from oxygen, has been particularly dwelt upon in this chapter, inasmuch as it is only the general principle of the storage of that energy in vegetable tissues which was to be here illustrated. The real processes, as they take place in nature, are infinitely complicated. It is not even known in precisely what way, nor in what proportions, the different kinds of solar radiation act in the processes of vegetation, though there is good reason to believe that the third of the three classes, namely, the *actinic* rays, act a very important, if not the most important part. The substances, moreover, both simple and compound, with which the sun has to deal, are infinite in number, and his modes of dealing with them in the different organizations of vegetable and animal life are infinitely varied. The forces brought into action, the separations, the changes, the combinations and recombinations which are produced, are absolutely without end. Though great numbers of scientific men have for the last

THE SUN SENDING WARNING.

quarter of a century been devoting their lives to the work of exploring this field, they all feel that the work is but just begun. The farther they advance, the more numerous are the vistas which open before them of regions of wonder and mystery into which they are not yet able to make their way.

The general principle, however, as explained in this chapter, is well established, and it is one that every well-informed man should understand, namely, that the world of vegetable and animal life is, in respect to the physical phenomena which it manifests, a system for gathering, and storing, and afterward transmitting and expending in various ways the energy derived from the sun. This energy is mainly received and stored by the action of vegetation, and is held in reserve in the tissues of plants. Through these tissues portions of it are transferred in the form of food to the organizations of animals, where it furnishes a supply of force for the vital functions of the animal system, and for the locomotive organs which animals require to have constantly in readiness for action. Other portions of this force remain in the tissues of the plants, whence they gradually pass off into the surrounding air as the plants slowly decay, or are preserved through countless ages in the substance of peat, or coal, or petroleum, to be ultimately brought into action for the purposes of man.

And what is very wonderful, if true, is, that even the organs of the brain, through which, in some mysterious way, the mind performs its functions, are, as is now supposed, dependent on supplies of this reserved force for their vigorous and healthy action. In other words, not only the senses of seeing, hearing, and the like, but the more purely mental operations of thought, of reasoning, of imagination, and of memory are performed in some mysterious way through the agency of organs which, in their healthful working, expend large portions of this force which has been received into the system with the food. This is wonderful, and it is a truth, if it is a truth, which is received at present with much caution by scientific men; but the evidence which is constantly coming into view strongly tends to establish it.

Thus the force of the solar radiation, in entering into our atmosphere and acting upon the surface of the earth, divides itself into a thousand streams, and sets in motion a countless number of different agencies. It blows in the wind; it falls in the rain; it rolls in the waves of the sea; it undermines and disintegrates the rocks along every shore; it constitutes—or, at least, sustains—the strength of the lion, the fierceness of the tiger, the patient toil of the ox, and even the sagacity of the elephant and the cunning of the fox; and in the mysterious mechanism of the organs through which alone the human mind can act, in the present state of its existence, it expends itself in producing the incessant and joyous activity of youth, and perhaps in sustaining the thoughtful reasonings and the far-reaching memories of age. It is thus the source and sustainer of almost every kind of action which we see taking place around us on the earth. In the dawn of human civilization, if the philosophers of those days had any glimpses of these truths, it would not, therefore, seem at all surprising that they established ceremonies of the nature of worship in honor of the Sun.

CHAPTER XIII.

SCIENCE AND SENTIMENT.

Those who have read the volume of this series entitled Water and Land will perhaps recollect that Lawrence had an acquaintance and friend named Theodora Random, a young lady of about sixteen years of age, who was generally away at school at New York, though she spent her vacations at home in the town of Carlton, where Lawrence was now residing.

Now this Miss Random had a cousin named Roundell, who was at this time a law student. Lawrence and Roundell were classmates in college, but after they left college their paths seemed to diverge, for Roundell commenced the study of the law, while Lawrence had chosen engineering in some of its branches as his pursuit in life, and had gone to a scientific institute to study mathematics and physics.

About the time that the incidents related in this volume were occurring, Roundell came to make a visit at Carlton, and he and Lawrence renewed their acquaintance with each other, and they took many walks, and held many conversations together in regard to their plans of life, and the professions to which they had respectively devoted themselves.

One pleasant morning, Dorrie, as Theodora was often called, conceived the idea of taking her pencils and paper, and her little sister Jenny, and going out into the woods to a place called the Cascade, on what she called a drawing excursion. Her plan was to find some pretty little object, or group of objects, that would form the subject of a design for her sketch-book.

Mr. Roundell, as it happened, came to the house to call upon his cousin just as she was setting out upon her excursion, and when he learned where she was going, he said that he would accompany her.

"Very good," said Dorrie; "only I am not going to have you look over me while I am drawing."

"And I will go and get Lawrence to go too," said Mr. Roundell, without noticing Dorrie's prohibition in respect to looking over her. "He likes such excursions."

"If you do that," said Dorrie, "you will do it on your own responsibility. You must consider it as against my express orders."

Mr. Roundell saw at once, by a certain sly and significant look upon Dorrie's face, that she was not in earnest in this; so he proposed that she should go on till she reached a certain place which he designated, and wait there until he and Lawrence came and joined her.

"Well," said Dorrie, "if you *will* go, you must, I suppose; but I hope you won't find him at home."

Mr. Roundell paid no attention to this, but went in search of Lawrence, while Dorrie, with a small portfolio under her arm, and her pencils in their case in her pocket, set off with her little sister to walk by another way toward the appointed place of meeting.

This place of meeting was a very pretty spot near a stream, where Lawrence had made a seat some time before, which seat had become a favorite resting-place for all the young persons of the village when walking in that direction. The seat was formed in a somewhat curious way. Lawrence had observed two young trees growing pretty near together, upon a smooth grass-plot in a place sheltered by quite a little grove growing behind it, and had conceived the idea of using those trees as a support for the back of a seat. So he bent the trees into the right inclination for such a purpose, and confined them in that position till they had become fixed in it. Then he put two short posts in the ground, one in front of each tree, and at the proper distance to form the breadth of the seat. He nailed cleats across from the top of these supports to the lower part of the trees, arranging the whole so that the plank which was to serve for the seat, when placed upon the cleats, should be at the right distance above the ground. He then procured a piece of plank long enough to afford room for two or three persons to sit upon it, and, after smoothing it and rounding the edges, he fastened it to the cleats. He also nailed a narrow board against the trees at the proper height to form a support to the back for persons not quite full grown.

Thus he formed a very comfortable and quite a durable seat; and as it was in a very pleasant spot, pretty open, though sheltered by a grove in the background, and not far from the stream at a spot where the water fell over the rocks in the bed of it in quite a picturesque manner, it is not at all surprising that "Lawrence Wollaston's seat," as it was called, soon became a favorite resting-place for young people making excursions in that region.

The trees, moreover, notwithstanding the nails driven into the stem of them, continued to grow, and, as Lawrence watched the growth of the new shoots from the top from time to time, and trimmed them a little as occasion required, he gradually aided the trees to form a sort of canopy of foliage over the seat, which greatly added to the attractiveness of the place, especially in warm and sunny days.

It was at this place, as has already been said, that Miss Random and her sister were to wait for Mr. Roundell and

Lawrence, and there the two young men in due time found her. When they came to the spot, however, although they saw Miss Random upon the seat, they did not see Jenny any where near. As they approached toward her, Dorrie nodded to them. Lawrence bid her good morning, and said,

"I am very glad to see you. How do you do this morning?"

"Pretty well," said Miss Random, "only cross."

She said this with something like a pout upon her lips, and something still more like a twinkle in her eye. At any rate, there was something in the expression of her face that led Lawrence to think that her vexation was pretended rather than real.

"What makes you feel cross?" asked Mr. Roundell.

"Why, I came away from home," said Dorrie, "and forgot my India-rubber, and so I had to send Jenny back for it, and she has been gone ever so long; and that makes me feel cross and contrary. I hope that one or the other of you will say something that I can have a chance to contradict—especially Mr. Wollaston," she added, looking up to Lawrence with a half smile upon her face.

"Why, I thought you liked Mr. Wollaston," said her cousin, "or else I should not have brought him."

"I like him well enough," said Dorrie, "if he wasn't so dreadfully scientific."

"You don't like science, then?" said Mr. Roundell.

"No," said Dorrie. "I think it is horrid. It makes every thing in the world so matter-of-fact like and commonplace. Look, now, at this beautiful stream. Before people knew any thing scientific about it, what a charming thing it was. They followed it back till they found it coming out of the ground in a fountain, boiling up in a most mysterious and wonderful manner. They imagined it the work of nymphs and naiads, that had magic power over it, and gave all sorts of wonderful virtues to the water. All its sparkles were their smiles, and its ripples, and bubblings, and whirlings were their play, and its murmurings and purlings their fairy talk. It was all charming. But now all this is gone. The fountain is nothing but an outlet for the rain that has soaked down into the ground among the mountains, with grass and weeds growing round it, and the stream itself only a big drain, to drain off the rain-water into the sea."

Mr. Roundell and Lawrence both laughed here, being somewhat amused at Miss Random's idea of the belittling effect of scientific knowledge in respect to our conceptions of the grand phenomena of nature.

"And then thunder and lightning," continued Dorrie, with a triumphant look and tone, and turning toward her cousin. "He explained it to me the other day; and what do you think he made it out to be? Why, nothing but a big spark of electricity, precisely such as he makes by rubbing a long Cologne bottle with a silk handkerchief—only a little larger and brighter."

"A *little* larger and brighter?" repeated Lawrence, in an interrogative tone.

"Well, a *good deal* larger and brighter, if you please," said Dorrie; "but just the same thing, in fact, as any little snap from his electric machine, or like the sparkles we see when we rub a cat's back in a dark closet. Think of making it out that a bright flash of lightning, dazzling your eyes and setting the whole sky in a blaze, with a tremendous peal of thunder coming immediately after it, and frightening you half out of your senses, is really nothing different from the sparkles you see in a silk stocking when you take it off in the dark."

Dorrie said all this in a jocose and good-humored way, showing that she was talking for the sake of talking rather than to express any serious opinion that she really entertained.

"Now, you see," she continued, "before the scientific men came in to discover and explain every thing, people often had grand and sublime ideas in respect to the wonders of nature, and the sublimity and grandeur were greatly increased by the very mystery of them."

"Yes," said Lawrence, "that is a very fair statement of the case. It is a question between the pleasure of ignorant wonder and intelligent understanding."

Miss Random paused a moment on hearing these words, and seemed to be thinking of them.

"There is one thing I should like to know, at any rate," said Miss Random, after a moment's reflection, "for I think it goes against your theory of lightning and electricity being the same. We get electric sparks most easily in cold and dry weather, as, for example, in cold and clear winter nights; but we never have thunder-storms at such times; they always come in warm days and in showers of rain. This shows that they are different things."

Now it is always very important, when we are conversing with persons younger than ourselves, and they ask a question, to determine, before we attempt to answer it, whether the inquiry which they make is really a request for information or an *argument* in disguise. If it is really a request for information, your answer will be listened to, and, if satisfactory, will be understood and received. If it is an argument in disguise, your answer will scarcely be heard, and, if heard, will be very little attended to. In such cases, the question is asked with the expectation and hope that it is unanswerable, and if you attempt to answer it, the mind of the person who asked it is shut up against receiving the explanation that you give. It is usually better, therefore, not to attempt to answer such difficulties at all, but to admit whatever of force, or of seeming force, there may be in them, and leave the point in question without any attempt to explain it. It is a very difficult thing for us to make people see a thing when they do not wish to see it, and especially when their seeing it would deprive them of a triumph over us, which they had anticipated, and would give us a triumph over them.

Teachers of classes in Sunday-schools have often occasion to observe this distinction, for their pupils often ask them questions, not from an honest desire to have a difficulty removed, but to show off their own acumen in discovering it, and pointing it out, and sometimes even with a secret wish to embarrass and perplex the teacher with the insuperableness of it. Of course, a mind that is in that state will receive no benefit from any instruction or explanation offered to it, and any attempt to offer instruction would be vain. It would be met by resistance more or less open, and the conversation would end either in a sullen silence on the part of the inquirer, or in perfectly useless discussion.

Now Lawrence, like other young men of his age, sometimes did very foolish things, but he very seldom did any thing quite so foolish as to get into a discussion of this sort with a lady. So, when Miss Random argued that the thunder and lightning of the heavens could not be of the same nature as with the electric cracklings produced by friction, from the fact that the phenomena of the latter kind are more commonly produced in clear, cold winter weather, while the former are almost entirely confined to the hottest season of summer, and when, moreover, the whole atmosphere is filled with the falling rain, he offered no counter argument in reply, but rather fell in with the view which she had expressed.

"That is true," said he. "I never thought of it before in the precise light in which you now present it. Dryness and cold seem most favorable for producing electricity by friction, while we seldom have lightning except after a hot day and in the midst of pouring showers. Dr. Franklin was the man who first proved, as he thought, that the two things were the same, and if he were alive now, and I knew him, I would go and ask him what he had to say in respect to that difficulty."

Miss Random had been perfectly good-humored in all that she had said, and she was confirmed in this amiable frame of mind by finding her difficulty treated with so much respect.

While they had been talking in this way at the seat, Theodora's sister Jenny, who had been sent back for the India-rubber, had returned, and, finding the party engaged in conversation, had very discreetly taken care not to interrupt them, but had come and laid the India-rubber down gently in her sister's lap, and had gone down to play on the bank of the stream. So Theodora rose from her seat, and said that, as Jenny had come, they might as well go on.*

"And when I come to a place where I see any thing pretty to draw," she said, "you shall find or make me a seat somehow, and while I am drawing you can go and collect your specimens of botany or geology."

So the whole party began to walk on.

"And if you find any pretty flowers," added Dorrie, "you may bring them to me, only don't bring me any of the barbarous Latin names of them. I don't see what the use is of the Latin names, anyhow.

"Look, now, at that pretty little white clover," she added, pointing down to the side of the path; "what do you call a white clover, now?"

---

* See Frontispiece.

"The botanical name of it, I believe, is *trifolium repens*," said Lawrence.

"And what is the use of calling it by such a name as that?" said Dorrie. "Why not call it white clover and done with it? I am sure it is a great deal prettier name than *trifolium repens*."

"That is true," said Lawrence. "I like the name white clover better for some purposes."

"For what purposes?" asked Dorrie.

"Why, when I am talking about the plant to farmers or to children, because they know it by that name, and do not know it by any other; but when I am thinking of the plant myself, I like best to think of it as *trifolium repens*, for that is the name that it is known by all the world over. In thinking of it by the name that educated men know it by in France, and Germany, and Italy, and India, I put myself, as it were, in a kind of relation to them, and in imagination make myself one of them, as it were, and form a part of their company. It is a mere imagination, I admit."

"Yes," said Dorrie, "I think it is."

"But it is a very pleasant feeling, for all that. A great many of our pleasures are those of the imagination. They depend upon the form in which ideas lie in our minds."

Dorrie was silent. She felt that there was some force in what Lawrence was saying, but she did not think there was *much* force in it, after all.

"Well," she said, presently, after a short pause, "you must not think, cousin, that I quarrel a great deal with Mr. Wollaston about his science. I think there is *some* sense in it."

She said this with a sly smile upon her face, which plainly indicated that she was speaking jocosely.

"It is all a question," replied Lawrence, "as I said before, between the pleasure of wondering ignorance and intelligent understanding. When a child sees a magician put a rabbit under a box, and then, in a moment, lift the box and finds that Bunny has mysteriously disappeared, his astonishment and wonder are excited, and they are feelings which give him pleasure. When, however, the manner in which the trick is performed is explained to him, the wonder is all gone, and another pleasant feeling comes in to take its place—that of understanding the process by which the feat is performed. If, now, another child, who knows nothing about it, goes with him to witness the performance, and they sit together and see the rabbit disappear, one has the pleasure of wondering at the mystery, and the other that of understanding the secret. I don't know which you would consider the greatest."

"I think the pleasure of wondering is the greatest," said Dorrie.

"Very likely," said Mr. Roundell; "but the pleasure of understanding is the *highest.* The child that knows how the trick is performed feels that he stands on a higher level than the other, who only wonders at the inexplicable mystery of it."

I think that Mr. Roundell was right in this opinion. It is often a very pretty thing for a child to stand upon the shore of a brook, and see the water flow by, and play with the pebbles and flowers upon the brink. And I do not deny that there may be a certain feeling of pleasure in his wondering at the mystery of such a stream, in not knowing where it comes from and where it is going to. But when the child is afterward taken to the summit of a neighboring hill, and traces the course of the brook in its meanderings down the mountain ravines to the place where he had stood upon the bank, and follows it below as it goes on gradually widening and receiving other brooklets on its way, till it finally flows out into the river or into a lake, the pleasure which he feels is of a higher kind, if not greater in degree, than that which he felt before. His field of view is enlarged, his ideas are expanded, and he has raised himself to a higher position, intellectually, by the new knowledge which he has acquired.

It is substantially such a change as this that we pass through at every step we take in becoming acquainted with the true character and significance of the natural phenomena which we see taking place around us.

"But you think," said Mr. Roundell, resuming the conversation after a moment's pause, "that the pleasure of wondering about a mystery is greater than that of understanding the explanation of it?"

"Why—no—not exactly," replied Dora; "and you must not think that I seriously have any fault to find with Mr. Wollaston's science. I like it well enough. Indeed, I have learned a great many things that I like very much to know."

"She's a charming pupil, at any rate," said Lawrence.

Dorrie would not have been by any means so ready to make this acknowledgment, which was, indeed, a half retraction of what she had said before, if Lawrence had resisted her, and allowed himself to get into an argument with her on the subject. It was one of the numerous cases in which the quickest and most effectual way to disarm your antagonist, and lead him to yield, is to cease your resistance to him.

"I take a much greater satisfaction, for instance," continued Miss Random, "in looking at the telegraph wires along the roadside now that I know, as Mr. Wollaston explained it to me, that nothing passes along them but a succession of impulses—some kind of electrical impulses. I used to think that letters and words passed along somehow or other, and I wondered how it could possibly be. It was nothing but ignorant wonder, as Mr. Wollaston says.

"But he explained to me that there are really no letters, or words, or any thing of the kind that pass along the line, but only a series of electric pulsations, in sets, each set denoting a particular letter, and they make out the letters and the words at the end of the line."

"How do they make them out?" asked Mr. Roundell.

Mr. Roundell was a very intelligent and well-informed young man, but there are a great many intelligent and well-informed men who have no clear idea of how the electric pulses that pass along the wires are translated into intelligible words and sentences at the end of it.

"Why, the wire at the end is coiled round an iron rod," said Miss Random, "and every time a pulsation passes it it makes the rod a magnet, and it pulls a little clapper, and the instant that the flow is past it lets the clapper drop again, and so, by hearing or seeing the motions of the clapper, they know what sets of pulsations are passing, and so can make out the letters and words."

"I should think it would be very difficult," said Mr. Roundell.

"It *is* very difficult," replied Lawrence, "and it requires a great deal of instruction and a great deal of practice to make a good telegraphic operator."

"But there is one thing I don't understand," asked Miss Random, "and that is, how the electricity makes the iron a magnet just by passing round it through a coiled wire. It is electricity in the wire, and magnetism in the rod. Does the electricity turn into magnetism, or does it wake up the magnetism that is in the iron already, or how?"

"Ah!" replied Lawrence, "there you pass beyond the bound of our present knowledge—at any rate of mine. All we know is the fact that, in some mysterious way, a current of electricity, in passing *across* a bar of iron, tends to develop a magnetic force in it; and if it passes across it a great many times, as it does in being wound around it in a coil, the development of magnetism is all the stronger. Nobody has found out yet what the secret working of the process is."

"So there's where the ignorant wonder comes in again," said Dorrie.

"That's a fact," said Lawrence.

"I don't see, then, that you gain much, after all," said Miss Random.

"We certainly do not gain any thing," said Lawrence, "in the way of reducing the number of the subjects of mystery and wonder in the phenomena of nature around us. We gain the advantage of an intelligent understanding of some parts of the process for a certain distance. The satisfaction which this affords increases as our investigations go on and our horizon enlarges. But we are sure in the end, whatever the path which we follow, to find ourselves on the verge of a region of mystery and wonder that we can not penetrate. Intelligent understanding is better, as far as we can go with it; but, in whatever direction we may go, we are sure to come to a region where there is nothing for us but wondering ignorance at last."

CHAPTER XIV.

THE SUN.

There is perhaps no case in which, in our attempts to investigate the phenomena of nature around us, we are brought sooner into the condition of wondering ignorance than that of the sun. We know it, it is true, as the source of almost all the forces of every kind which we see in operation in the earth around us. This force comes from it in a perpetual, an enormous, and, apparently, an undiminished supply; but on the principles now admitted, that force can not be increased or diminished, and can by no possibility come into existence out of nothing, the question at once arises, What is the source of this supply?

And here we have to enter at once into the region of ignorant wonder that Lawrence and Miss Random spoke of in their conversations; for it is a remarkable fact that, though the sun may perhaps be considered as in some sense the most conspicuous object in nature, and the most open to the observation and even to the full scrutiny of man, it is yet the object which of all others is involved, in respect to its constitution and the character of the various phenomena which it presents, in the most absolute and impenetrable mystery.

The point, however, which we have to consider in this chapter is simply whence the sun derives the enormous supply of force which he is now and has long been radiating. The quantity of this force, like most of the quantities with which astronomy and other sciences connected with it are concerned, wholly transcends the powers of human conception, so that the numerical statements concerning them are rather matters of curiosity than means of conveying any definite ideas to the mind.

The distance of the earth, then, from the sun being about ninety millions of miles, the sun's rays must, of course, be diffused at that distance over the surface of a sphere *one hundred and eighty millions of miles* in diameter, and this, it is found by computation, comprises an area of *thousands of millions of millions of square miles*—a space so vast that the portion of heat and light which would be intercepted by so small a body as the earth would be inconceivably minute. Herschel made a calculation to determine what the proportion would be, and he found that the quantity of solar force received by the earth was so exceedingly small, when compared with the whole amount emitted by the sun, that the fraction expressing it conveys no idea to the mind of the general reader. The fraction is $\frac{1}{215,000,000}$.

What an enormous reservoir of power, then, the sun must contain, if so exceedingly minute a portion of it can produce all the effects which we see taking place around us on the globe!

And thus, while it is very difficult for us to comprehend how extremely minute a portion of the solar force falls upon the earth relatively to the whole amount emitted, it is equally difficult to appreciate how immense the amount is, absolutely, that the earth does thus receive. The most careful observations and calculations have been made to determine this amount, and it has been ascertained that the total quantity emanating from the sun, and received and expended upon *every acre* of the earth's surface, or in the atmosphere above it, is equal to that represented by the continuous labor of *one thousand horses!*

A large portion of this force is employed in evaporating water and producing changes in the atmosphere. Another large portion is absorbed by the organs of vegetation and stored in the tissues of plants; and a third remains as heat in the surface of the ground, to be radiated again into space when night comes or when the season changes. But no practical method has yet been devised for intercepting and utilizing this force at once on its arrival by applying it to mechanical purposes. Many scientific men, however, and especially the naval engineer, Ericsson, believe that this will some day be done, and that we shall then cease to be dependent, as we are now, on the stored force of coal received from the sun in former ages.

Several experiments have, in fact, been made with a view to ascertain the present practicability of so gathering and concentrating the solar radiance as to make it applicable to the purpose of driving machinery; such concentration is necessary; for, though a force equal to that of a thousand horses is received within the area of an acre, that which would be included in any small area, like that occupied by the fixtures and appurtenances of a steam-engine, would be too small to produce any useful mechanical effect. A French mechanician, however, succeeded a few years ago in so concentrating the sun's rays by means of reflectors as to drive a small hot-air engine by the heat derived from them.

Now, when we consider that a force is continually flowing from the sun equal to that of a thousand horses on every acre of the earth's surface, and yet that the amount that is intercepted by the whole earth is only about *one two hundred millionth* of the quantity that is emitted by the sun, and that this immense emission has now been going on not only for the six thousand years of history, but, as there is every reason to believe, for millions upon millions of ages before, we see at once that there must be some mysterious source of supply of a magnitude transcending all possible human conception. What is the nature of this source of supply no one knows. In the absence of any thing like positive proof of what the origin of this vast and inexhaustible energy actually is, all the light we have upon the subject consists of conjectures and speculations as to what it may be. The principal theories that have been advanced are these:

1. That the sun is a hot body cooling.

2. That it is a combustible body burning.

3. That it is an inert mass heated and kept hot by a succession of blows.

1. That the sun is a hot body cooling. This was the most obvious thought, and the one first adopted. It is true, it only removed the difficulty one step farther back; for, even if there could be heat enough contained in such a mass as that of the sun to endure for so many ages, the question would arise, By what process could such a hot body have been formed in the centre of the solar system? But then this is the final result of all our discoveries and explanations of natural phenomena. We only remove the difficulty one or more steps back. We can never, by mere scientific investigation, arrive at any beginning.

This theory is, however, in its original form, now generally abandoned; for it has been shown that radiation from such a mass at the rate at which the radiation from the sun is now going on would, according to all known laws of radiation, exhaust the supply so rapidly as to produce a total change in the effects of it in the course of a far shorter period than even the six thousand years of history.

A theory, however, which is in some respects a modification of this original idea, has been recently advanced, and that is, that the sun may be a vast mass of gaseous matter—enormously compressed, it is true, but still retaining its gaseous condition—which is in the process, as it cools, of *gradually liquefying.* In such a process it would, of course, give out in radiation not only its heat of *temperature*, but also its heat of *vaporization.* This is substantially the same process that takes place in warming a house by means of steam. The steam from the boiler carries into the pipes not only the heat of its temperature, but also that of its *vaporization*, and this, as well as the other, it gives out by its condensation in the pipes. If it were *air* instead of steam that was conveyed into the pipes, though it might be of precisely the same temperature, it would give out comparatively little heat, namely, only that of its temperature—that is, the amount necessary to cool it; but the pipes must abstract from the steam not only enough to cool it, but also the enormous additional quantity necessary to *condense* it—an amount equal, as we saw in a previous chapter, to not far from a thousand units to the pound.

This supposition, that the body of the sun is composed of a gas in the process of being liquefied by the radiation of both its sensible and latent heat, would account for the continuance of the radiation for an immensely longer period than would be required for the cooling of a body without any change of state, but the origin of the supply would remain as great a mystery as ever.

2. The second of the three theories I have named is that the sun is a *combustible body burning.*

Now combustion is the name we give to certain kinds of chemical action so intense, in respect to the degree of force with which the elements concerned come together, as to produce an abundant evolution of light and heat—that is, of force in those forms. Now the quantity of force thus liberated is that which has been already described as the heat of *dissociation*, which, as we have seen, is vastly greater than that of vaporization; that is, the heat required for separating the particles of water from each other so as to convert the substance from the liquid to the gaseous state, though very great, is enormously surpassed by that required for separating the particles of oxygen and hydrogen from each other in decomposing the water. It requires, as we have seen, nearly 1000 units of heat per pound to vaporize water, and something like 50 or 60 thousand to separate the particles of the vapor into their original elements. Thus, instead of regarding the sun as a hot body, cooling itself by radiating its sensible and its latent heat—giving out in the latter its *heat of vaporization*—this second theory views it as a combustible body burning; that is, as a mass of different substances having so strong a chemical affinity for each other that they combine with great intensity of action, so as to give out, in the form of light, heat, and actinism, the whole of the immense force required to separate such substances in decomposition, and thus provides an immensely more copious source of supply. By this latter supposition a vastly greater and more enduring heat is provided for than by the former, just as a mass of coal in *burning* will give out a vastly greater quantity of heat than a mass of iron would, of the same weight, in simply cooling from the same temperature.

But the quantity, after all, would not be enough to account for so long-continued and so enormous a supply of force as that which has been coming for so many ages from the sun. The most careful calculations have been made, and it has been shown conclusively that if the sun were a mass of coal, the combustion of it would not afford force enough to account for the solar radiation for but a very small portion of the long period during which we know that the sun has been shining with at least the present fervency of its beams.

3. The third theory which has been advanced is that the sun is *an inert mass kept hot by a perpetual succession of blows.* These blows are supposed to be given by masses of meteoric or other matter constantly falling upon it, and striking with prodigious violence as they fall.

It has been shown in a former chapter that whenever two masses of matter strike each other, the extinguishment of the motion thus resulting is accompanied by a development of heat, and also, when the collision is sufficiently violent, of light, and perhaps of electricity, and of other forms of energy. Thus a blacksmith can heat a bar of iron red hot by simply hammering it upon an anvil, and a ball from the gun of a siege train, when it strikes the wall of the fort attacked, is so heated by the sudden extinction of its motion as at night to emit a flash of light that is plainly visible. It is calculated that the heat produced by the impact of a leaden bullet upon a solid wall would be sufficient to melt the lead, if it could all be imparted to the bullet, instead of being divided between the bullet and the wall.

Nor does it make any difference in the *proportional* effect whether the bodies impinging against each other are large or small, or whether the force with which they strike is violent or gentle. The quantity of heat which is evolved depends simply upon the quantity of motion extinguished, so that a flake of snow descending ever so gently upon the grass, and stopped by the collision, warms itself and the grass by the extinction of its motion, just as much, in *proportion to its weight and the velocity of its descent*, as a 500-pound iron ball in crashing against an iron-clad wall of masonry.

Now there is every reason for believing that the region of space included within the preponderating influence of the sun, and within which the planets move, is very far from being occupied solely by these visible orbs. The hundreds of minor planets that have recently been discovered, the thousands of millions of meteors and comets—for a distinguished astronomer proved that there were more comets in the space within the influence of the sun than there were sands upon the sea-shore—show that there is revolving about the sun at all times a quantity of matter, in various forms, wholly inconceivable in amount. And if the space through which these masses move is filled, as there is every reason for believing that it is, with some resisting medium, they must be gradually drawn nearer and nearer to the sun in their orbits of revolution, and there must be all the time vast numbers of them falling into it, and in thus falling into it, their motion, by its extinction, must be converted into heat. The only question would seem to be whether there can be a sufficient quantity of such matter falling into the sun to develop, by the resulting concussion, the quantity of heat necessary to supply the enormous emanations.

There is one important thing to be considered in respect to this point, and that is, that it makes no difference in regard to the amount of heat that would be evolved by a body falling upon the sun, whether it strikes upon a solid surface or plunges into a liquid or a gaseous one, for we may even suppose the sun to be composed of a gaseous substance enormously compressed. In the case of a solid, the motion would be almost instantaneously extinguished. In the case of the foreign body plunging into a liquid or a gas, the extinction of the motion would be more gradual; but in both cases the amount of extinction of motion, and the whole quantity of heat resulting from it, would be the same; only, in the former case, the heat would be more suddenly produced, and would appear more directly at the spot on the surface where the impingement took place, whereas in the other it would be more gradually developed, and would be diffused more generally through the mass.

Another thing to be considered is that a body falling into the sun would fall with a very much greater force than one descending from a corresponding height upon the earth; for, on account of the immense mass of the sun, the effect of gravitation on its surface is between twenty and thirty times as great as that exercised at the surface of the earth; so that the force with which a falling body would strike—that is, the amount of motion that would be extinguished by the collision—and, consequently, the amount of heat that would be generated, would be vastly greater than that which would be produced by the fall of a similar body upon the surface of the earth.

Now the most laborious calculations have been made by certain German mathematicians and astronomers, based on very careful and long-continued observations, to determine what the probability is in respect to the quantity of matter that is thus continuously arriving at and falling into the sun, the velocity with which it would be moving at the time of collision, and the quantity of heat which would be developed, and the result is very strongly confirmative of the theory in the minds of a great number of scientific men. It has been shown by very careful computations that the velocity with which a revolving body, large or small, would ultimately sink into the sun, would be not less than 400 miles *in a second*, and that the quantity of matter that would be required to maintain the present radiation from the sun for 2000 years would form a layer upon his surface of less than twelve miles in thickness, which would increase the diameter of that orb by an amount that would be wholly imperceptible under the nicest observations at this distance.

There are, however, many scientific men who are far from being satisfied with this explanation, so that the question must be considered as still in doubt. All we have to do at present, therefore, is to make ourselves acquainted with such facts in regard to the constitution and condition of the sun as have been observed, and hold our minds somewhat in suspense in regard to the true explanation of the phenomena until more light shall be obtained.

It is well ascertained that it is only the central and brighter portion of this body which is directly observable by us, and this gives it the appearance of a well-defined spherical mass, excessively brilliant, but in a state of calmness and repose. But it has been found within a few years, and especially by means of observations during periods of total eclipse, when the whole of this central portion is con-

APPEARANCE DURING A TOTAL ECLIPSE.

cealed from view, that instead of having a distinct and definite quiescent boundary, the whole vicinity of what has been supposed to be the boundary is filled, to the height of many thousands of miles, with a boiling, flaming, furious mass, in a state of the most intense and violent action.

And the indications of this and similar action are seen extending themselves over the whole surface of the orb, which seems to be furrowed with incandescent billows in a state of incessant motion. Enormous flame-like coruscations, in masses larger than this globe on which we dwell, rise, and glow, and wave, and then melt away and disappear. Some of these blazing radiations appear to project themselves forty or fifty thousand miles into the surrounding space, though, on account of the immense magnitude of the body of the sun, and his vast distance from us, they do not perceptibly affect the smoothness of the contour of his disk, as it appears from the earth to our unassisted vision; but the real violence and rapidity of the action thus taking place are inconceivable. On the one hand, cavities of apparently absolute darkness, and, on the other, vast protuberances of extraordinary and special brightness, form and fluctuate over the surface, increasing and diminishing at the rate of thousands of miles in extent in very brief periods of time.

Thus the sun, instead of existing in the calm, placid, and unchanging condition which it appears to assume, is in reality a mass of seething and surging incandescence, deformed by incessant and tempestuous agitations of surface, produced by contests among forces the nature of which elude our research as completely as the enormous magnitude and extent of their effects surpass our powers of conception.

Among all the phenomena denoting the incessant disturbance and change which is taking place in the condition of the solar surface, what are known as the spots, or *mac-*

ulæ, as they are termed by astronomers, which are sometimes large enough to be seen by the naked eye, first attracted the attention of mankind, and have been a very fruitful subject of speculation in all ages.*

It was for some time a matter of doubt whether the appearance of spots was due to something actually attached to and forming a part of the sun's surface, or whether they were caused by opaque bodies revolving in space at a distance from the sun, and passing across his disk from time to time, so as to intercept a portion of his light. That the former supposition was the true one soon seemed to be proved by the fact that when the spots disappear on one side, and then afterward reappear again on the other, which often happens, the interval of disappearance is always the same as the time that they continue in sight. This evidently could not be the case if the phenomena were due to bodies revolving at a distance from the sun, since it would be only a small portion of the orbit of such bodies that would come between us and the disk in the course of its revolution, and, consequently, the times of appearance and disappearance would be very unequal.

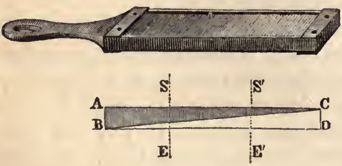
The spots on the sun are sometimes, though not very often, of such magnitude that they can be seen by the naked eye. To make it possible to look directly at the dazzling surface, astronomers employ darkly-colored glasses to intercept a portion of the rays. By ordinary observers, glass covered with a film of smoke, by being held in the flame of a lamp or candle, is used.

The smoked glass answers the purpose sufficiently well for sudden and temporary emergencies; but for permanent use astronomers employ a helioscope, which is much more

---

* In addition to the *maculæ*, there are certain lines of superior and excessive brilliancy often seen in the vicinity of the spots, which are termed *faculæ*, from a Latin word signifying a *small torch*.

convenient. This instrument consists of two wedge-shaped plates of glass—one of a very dark color, and the other perfectly transparent—made to fit each other very exactly, and set together in a suitable frame, as shown in the engraving. The frame is rectangular in form, and of a width and length convenient for the eyes, and is provided with a handle. The plates of glass are so fitted together (as shown in the second figure, which presents a sectional view of them) that the thick part of one plate, ABC, lies upon the thin part of the other, CBD. The thickness of the glass, therefore, through which the rays have to pass is the same every where, and there is, therefore, no refraction to distort the image, while by moving the instrument along before the eyes the image may be made more bright or more obscure at pleasure. At SE, for example, the rays pass through a greater portion of the dark glass than at S'E'.



THE HELIOSCOPE.

These simple contrivances answer very well for viewing the sun with the naked eye; but great difficulties have been encountered by astronomers in devising effectual and convenient means of enfeebling the rays in the use of powerful telescopes. Some kinds of colored glass, it was found, intercepted the rays of light, but allowed the heat to pass freely; while others, which absorbed the heat, did not sensibly diminish the dazzling intensity of the light. Without great care, moreover, the plate or plates of colored glass, by a more or less irregular refraction of the rays, affected unfavorably the distinctness of the image.

These difficulties have at length been in part avoided and in part overcome in the use of an arrangement by which a magnified image of the sun is received upon a white screen, like the picture in a camera obscura, where it can be studied in all its aspects and peculiarities by the observer at his leisure, and drawings and photographs taken with great facility.

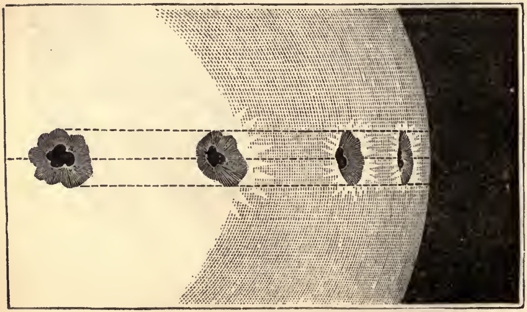
The spots, some of which are almost always to be seen

GENERAL APPEARANCE OF THE SPOTS.

by means of powerful telescopes, are of the most fantastic forms; but, with few exceptions, each one consists of an apparently black central portion, surrounded by a gray or semi-luminous border, which is called the penumbra; and usually, like clouds floating in the sky, they change their form from day to day as they are borne slowly along by the revolution of the sun. They are sometimes small and circumscribed in form, at others extremely irregular, spreading into the most fantastic forms, but always, or nearly always, bordered by the penumbra.

Many of these spots, though occupying but a small space apparently upon the sun's disk, are really of immense magnitude. Vast numbers of them are so large that if, as has often been supposed, they are cavities in a luminous envelope surrounding the sun, a body of the magnitude of this earth might be dropped into them without touching the sides; and some, that have been observed and measured, would admit in this manner bodies of from fifty to a hundred times the bulk of this globe.

The evidence which led many astronomers to conclude



APPEARANCES INDICATING CAVITIES.

that the spots are of the nature of cavities, and not of protuberances upon the surface of the sun, is derived from certain peculiar changes in the form of the spot, which take place as it passes away from the centre of the disk, where it is presented directly to view, toward the limb, where it is seen obliquely. These changes are rudely represented in the preceding engraving.

It is plain that if the spots were protuberances—the penumbra surrounding them forming the sides—the portion of the penumbra lying to the *right* of the spot would gradually become concealed, while that on the *left* side would come more and more directly into view, as the spot moved from the centre toward the right limb of the sun as viewed by the spectator. The contrary is, however, generally found to be the fact, as shown in the engraving. This phenomenon is often referred to as proving satisfactorily that the spots are of the nature of cavities opening in some kind of bright gaseous or liquid envelope surrounding the sun, and disclosing a view of something dark, or at least of something having the effect of a dark object on our vision. It is not, however, considered absolutely certain that there is not some illusion about these appearances. However this may be, the vast luminous envelope which the sun presents to our view, endued with such exceeding brilliancy, and in a state of the most intense and violent commotion, is the source from which the heat and light that emanate from the sun seem to be derived, and is called the *photosphere.*

The photosphere, as this supposed igneous envelope forming the radiant surface of the sun is called, is popularly conceived of as existing in a calm, tranquil, and unchanging condition, though constantly pouring forth streams of heat and light of such intense and dazzling brilliancy. As seen without any scientific aids to the vision, this is the aspect which it presents; but, when viewed through powerful telescopes, this seeming quiescence and uniformity disappears, and the whole surface, as has already been said, is found to be in a state of the most violent action and agitation. The surface becomes variegated, too, by forms and figures of different degrees of brilliancy, which are continually varying in contour and position, and melting into each other in changes which, to be seen at all at such a distance, must be produced by movements of enormous magnitude, and of vast rapidity of action. The general surface is every where mottled with a kind of brilliant efflorescence, and in the vicinity of the spots a mysterious configuration appears called the *willow leaves*, from the resemblance to a group of willow leaves lying on the ground. In some parts these leaves lie mingled confusedly, crossing each other in every direction. In other parts, especially in the *penumbræ* of the spots, there is a tendency to regular arrangement, and especially to a convergent direction toward the centre of the spot. Sometimes lines of these figures extend out *across* a spot, forming what Nasmyth, the astronomer who first observed them, named *luminous bridges.* The engraving representing these appearances is not a fancy sketch, but an exact copy of a group of spots, and of the surrounding surface of the sun, as seen by Nasmyth on the 5th of June, 1864.

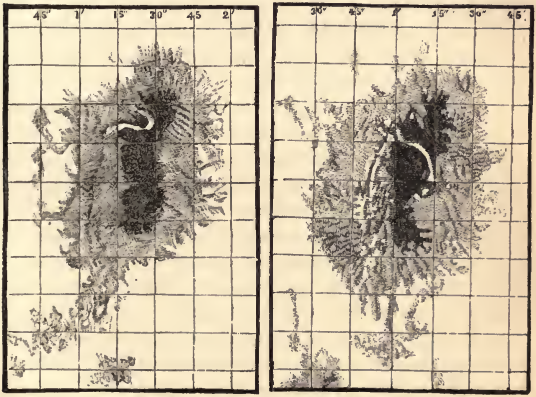
The mottled appearance of the photosphere, as observed by the aid of the most powerful telescopes, is still more distinctly shown in the next engraving, which records an observation made by Huggins. The granulations of light which form the mottling of the surface are of a form somewhat resembling grains of rice, to which they have sometimes been compared, and are very curiously grouped. The nature and the cause of them, as of every thing else re-

MOTTLED SURFACE. WILLOW LEAVES. LUMINOUS BRIDGES.

lating to the physical constitution of the sun, is enveloped in unfathomable mystery.

It is remarkable that the spots in the sun do not appear indiscriminately in all parts of the disk; they are chiefly confined to a zone extending some 30° or 40° on each side of the equator.

It is true that those existing at a distance from the equator toward either pole would be seen more or less obliquely, and would consequently come less distinctly into view. The smaller ones, situated far to the northward or southward, might, from this cause, especially if it should be true that the spots are of the nature of excavations or openings in a liquid or gaseous envelope, entirely escape observation; but, making all necessary allowances for this, it remains certain that the spots are due to some action among the constituents of the sun which is mainly confined to the equatorial regions of his surface.



Spot as seen Oct. 13, 1865. Spot as seen Oct. 14, 1865.

CHANGES OF FORM.

The changes of form and the movements of the spots may be very exactly observed and recorded by means of cross-lines in the field of view of the telescope. The engravings representing this mode of observation show the changes of form and position of a spot which passed over the disk of the sun in the fall of 1865, from drawings made by the English astronomer Howlet. On the upper margin of each figure, the divisions, in seconds, are marked for one *angular minute* of the surface; and by noting the relation of the spot to these marks, and to the lines drawn through them, the reader will perceive the changes, both in the forms of the spots and in their position, on the different days specified. It has been shown, by careful observations made in this manner, that the spots do not occupy a fixed position, as if pertaining to any solid portion of the orb, but that they have a comparatively slow motion upon the surface of it, as well as a motion *with* the surface in its regular rotation.

These changes of form and position, not only of the dark spots, but also of the bright lines and spaces which diversify the general surface of the sun, though seemingly gradual and slow, as they appear to us at the enormous distance from which we view them, are really effected with prodigious rapidity, and imply a continual and inconceivably intense action of some nature or other among the constituents of the photosphere.

But the most striking proofs of the prodigious intensity of the action which is taking place in the sun, and the enormous magnitude of the movements induced by it, are afforded, as has already been said, by the views which are presented at the time of a total eclipse. If the surface of the orb were really bordered by the smooth, well-defined, and quiescent, though dazzling envelopment which it seems to present to view in ordinary vision, the intervention of the moon, when the disk was entirely covered, would completely suppress the light from it during the brief period of totality, and, as it were, blot it out entirely from the heavens. But this is far from being the case. Although the whole *body* of the sun is covered, the figure of the moon intervening is surrounded by a remarkable halo of bright light, with protuberances, and radiations, and coruscations breaking out on every side, like vast volcanoes, or, rather, like rolling mountains of liquid fire.

These incandescent emanations are observed to be in a state of incessant movement. The changes of form and position are, of course, as seen from this enormous distance, apparently slow; the actions, however, in reality, take place on an inconceivably vast scale, and with enormous power and rapidity. In one instance an extremely brilliant coruscation was observed to surge across the disk at a rate which carried it, in the space of five minutes, over a distance of more than thirty thousand miles. How inconceivably vast must be the force of an agency which such a movement as this implies!

These coruscations and coronæ, formed of luminous emanations rising high above the surface of the sun, were observed very distinctly during the eclipse of the year 1869, and more perfect and exact representations of them were secured than has ever been possible before, on account of the very complete arrangements for photographing the effects which the observers had made. In various parts of the margin of the disk, rose-colored protuberances, like surging waves of fire, and coruscations shooting out for thousands of miles, like gigantic jets of flame, were seen by the eye and photographed by the instruments.

In addition to the knowledge which has thus been acquired by astronomers of the physical characteristics of the sun by observation with the telescope, a great deal of information has been obtained within a few years in respect to its chemical composition by means of what is called the *spectrum analysis.* A few words must be said in respect to this subject, though it is not very directly, or, at least, not very obviously connected with the subject of this volume.

A spectrum is a colored image produced by the separation of the light from any luminous source into its component colors by means of a prism, the effect of the prism being to refract the rays in different degrees, and thus to separate them from each other. Now the light, coming from different sources—as, for instance, from the sun, from a star, from an incandescent metal, from the electric spark, from the combustion of iron, or hydrogen, or zinc—is found, when separated in this manner by a prism, to produce spectra very different in appearance from each other; and when a peculiar apparatus is employed that is constructed with great delicacy and precision, certain *lines* appear—sometimes dark, sometimes bright—crossing it in great numbers and in a great variety of positions in respect to the length of the prism and to each other. This subject has been somewhat more fully explained in the volume of this series entitled *Light.* It is sufficient for our present purpose to say that the number, character, and relative position of these lines vary according to the nature of the incandescent substance which emits the light, its condition of aggregation—that is, whether it is in a solid, liquid, or gaseous state—and the character of the media through which it passes in coming to the place of observation. Many thousand of these lines are now known, and their significance understood. To the uninitiated observer, a map of any spectrum would exhibit only a succession of bands of bright color alternating with dark lines, forming a combination which, though exceedingly beautiful, would appear hopelessly complicated and unmeaning to a person first observing them, and yet to the spectroscopic scholar every portion of it speaks a language perfectly precise and clear. To him every bright band and dark line has a meaning, depending both on its character and on its position, which he readily and perfectly understands, while to all others it seems almost inconceivable that there can be any meaning in them, just as it would seem impossible to a savage, when shown a printed book, that such a complicated and interminable aggregation of apparently meaningless characters could possibly be the vehicle of communicating intelligence of any kind to any human mind.

And it is, indeed, a great study, that required to read and understand the language of the spectrum. Many men are employing themselves almost exclusively in these investigations. A society has now, at the time of this writing, been formed in Italy which is to be devoted entirely to the work of perfecting the spectroscopic apparatus and pursuing investigations by means of it, especially in relation to the constitution of the sun, and they have commenced the publication of a periodical for the sole purpose of communicating to the scientific world the results of their investigations.

The results that have been attained thus far show conclusively that many of the same substances that go to compose the mineral strata and the atmospheric envelope of the earth are found to exist in the sun, and also in many of the stars; and that the same laws which govern the action of light upon this planet are still in force at distances so enormous that, while light moves at the rate of 192 millions of miles *in a second*, it must have required, in some cases, 1000 years to traverse the distance between the place of its emission in some of these distant orbs to the spot where it enters the spectroscope and comes under the observation of man. What a proof this fact affords us of the vast extent, both in respect to space and duration, over which the same system of law which is now observed to be in action upon this earth exercises its dominion!

It is to be inferred from this that the same fundamental principles in respect to the nature and the action of force which prevail here prevail every where, and that the solar force, after passing through all the changes in form and character which we see exemplified in its various circuits over the earth, continues to be controlled in its action, after it is radiated away from the earth into the surrounding space, by the same laws which governed it while subject to our observation here. We can not follow it into these regions, nor discover the mysterious paths by which it finds its way back at last to the source from which it flows to us. We are somewhat in the situation of half-instructed inquirers into the philosophy of the river's flow. They trace the stream back to its source in a fountain issuing from the ground, which seems to furnish mysteriously a never-ceasing supply. They follow it in its downward course till it is lost in the boundless sea, but they know nothing of the wondrous way by which it or its equivalent finds its way back through invisible evaporation, and drifting clouds, and falling rain on the mountain tops, and infiltration through pervious strata, to begin its course through the fountain again. They have glimpses, it is true, of the clouds, and some ideas of their connection with evaporation from the sea, and with the fall of rain, but they have not yet learned to connect these phenomena together, and to see them as parts of the grand system provided by nature for the circulation of the waters of the globe.

In the same manner we trace back the continuous and unchanging flow of force which we see passing before us to its unfailing fountain in the sun. We follow it onward in the same way through all its circuitous paths, through the air, the water, and the organs of animal and vegetable life, until it finally passes off into the great ocean of space around us, but we can not yet see by what means, or through what paths, it or its equivalent finds its way back to replenish the great fountain of supply.

We have glimpses, it is true, of the action of force of some kind and in some forms—in the meteors, the comets, the auroral and zodiacal light, and other mysterious celestial phenomena. Meteors are seen at night, and even by day, shooting through the sky; and sometimes they seem

THE METEOR.

to enter the earth's atmosphere, where they are heated to incandescence by the friction of the air, and burst with frightful explosions, throwing down large fragments to the ground.

The zodiacal light is a luminous track or space seen in

THE ZODIACAL LIGHT.

certain seasons of the year, following the sun in the evening when he goes down, or preceding him in the morning when he rises.

There have been various surmises as to the cause and the nature of this phenomenon, but there is little known of it except that it is one of various forms in which the forces existing in the interstellar spaces are embodied. We have not yet learned to interpret the significance of these various phenomena, still less to connect them together, or to understand what part they bear in the grand system provided by nature for the circulation of force throughout the universe—a circulation which moves on in a perpetual flow of grandeur and majesty, never ending and never beginning.

CHAPTER XV.

RICK AGAIN.

There are various avenues through which the knowledge of external realities can enter the mind. When any thing is *told* us, the truth, so affirmed, enters through *the ear, and the organs connected with the ear*, in the brain. When we *read* it in a book, it enters through the eye. When we see it *illustrated in a diagram* or in a *pictorial representation*, it enters still through the eye, but through a different set of organs in the brain from those which take cognizance of the signification of words. Now, when a truth enters the mind by any two of these or other avenues, even if it is not apprehended any more clearly, it makes a much stronger and more lasting impression than when it enters only by one.

This is one secret of the great efficiency of illustrations on the blackboard, or demonstrations by experiments. Many persons imagine that these aids are mainly useful in conveying a clear understanding of the subject to the pupil's mind. But in many cases the great advantage is, not in enabling the pupil to understand the subject any better, but to deepen, and strengthen, and make more permanent the impression which the truth makes upon him.

For example, to take a very simple case, if in a school of young children you tell them that when a four-sided figure, with square corners, has all its four sides equal, it is called a square, and that when two of the pairs of sides are longer than the other two, so as to make it longer in one direction than it is in the other, it is called an *oblong*, they may all perfectly understand the explanation, but the *impression* which it will make will be very faint and evanescent. But if now the teacher draws the figure of a square, and also one of an oblong upon the blackboard, and writes the name of each in a legible and careful manner under it, so as to convey to the children the same truth which had before entered by words through the ear, now, by means of vision through the eye, it is not improbable that it would make an impression upon them so strong that it would never be effaced.

It is not so much the superior efficacy of one of these modes over the other upon which the results in such cases depends, but upon the *conjoint action* of the two. For if the teacher had merely drawn the two figures, with the names under them, upon the board, and had then only asked the children to look upon them long enough to observe the forms and to read the names, the impression would probably have been as faint and evanescent as before. The visible forms *must be accompanied* with the verbal explanation to secure the result.

And now for the application of these principles to our present purpose. These truths in respect to the origin of almost all terrestrial forces in the agency of the sun, which have been presented in a somewhat methodical and connected manner in the preceding chapters, had been explained and illustrated in a much more simple and familiar way by Lawrence to John and Rick Van Dorn, in various casual conversations that he held with them in their walks or fishing excursions. John had comprehended the subject pretty fully, and Rick had been much interested in some of the details of facts which Lawrence presented to his mind from time to time, though he had not made much progress in comprehending the full import of the general principles which were at the foundation of them. So Lawrence contrived a plan to present somewhat directly, in a visible form, the general truth that the sun stores force in plants which may be afterward evoked and made active by man.

Among his other articles of apparatus Lawrence had a small toy steam-engine, which was intended to be worked by means of an alcohol lamp placed under the boiler. He had had this engine for some time, it having been given to him when he was quite young. Connected with this he had a number of mechanical toys, some of which he had made himself. One was the figure of a man sawing wood, another represented a shoe-maker hammering upon his lapstone, and there were several others. These were connected with the piston-rod of the engine in such a manner that the engine, when in operation, set them all at work.

Now Lawrence told Rick and John one day that he had a plan for drawing force from the sun to work his little men, though he told them it would take some time to gather enough to do it. In saying this, he took some peas and beans, and planted them in a sunny place in the garden. Rick looked on while he did this, somewhat interested it is true, but much puzzled. He did not see at all what connection there could be between planting peas and beans, and gathering force from the sun to keep toy carpenters and shoe-makers at work.

Lawrence did not make much explanation at the time when the planting was done, but simply said, when the seed was in the ground,

"There! Now, as soon as they come up, the sun will begin to lay in force for me—to run my engine."

So they all went away, and Rick thought no more of the subject for two or three weeks. At length, one day, when Rick was in the shop, Lawrence said, "Let us go out into the garden, and see how my store of force is going on."

So they went into the garden, and found that the peas and beans were up, and growing quite large.

"Yes," said Lawrence, "every thing is going on very well. The sun is storing force in all these leaves and stems."

"I don't see any force," said Rick. "They are nothing but common peas and beans."

"And yet you'll see how I get the force out of them one of these days," said Lawrence.

The next time that Rick came, which was about a week afterward, Lawrence went with the two boys into the garden again.

"Yes," said he, "the experiment has gone on very well. I think there is force enough gathered."

So he cut off all the plants close to the ground, and carried the vines to a place where he could let them dry in the sun. This was necessary, for if he had evolved the force which was contained in the tissues, in the state they were then in, it would have been chiefly absorbed in the work of evaporating the water which was also contained in them, and the vapor which would thus be formed he had no means of confining so as to make it work his engine. So he left the vines to be dried by the sun—that is, he called, as it were, upon the sun to furnish the additional force necessary to evaporate the water, in order that he might have the use of all that was stored in the tissues for the work which he wished it to perform.

At length, some time afterward, when the vines had had time to become thoroughly dry, he made a somewhat complicated arrangement of apparatus for bringing this latent force into action in a manner to attract Rick's attention, and fix the truth which he was attempting to elucidate in his mind. He took a gun-barrel, which he kept among his apparatus to serve the purpose of an iron retort, and, gathering his dry vines in a paper, he crowded and rammed them into it until that part of the barrel that was to go into the fire was full.

Then he connected a flexible tube at one end with a cap which fitted over the muzzle of the gun-barrel, and at the other end with a small metallic pipe which he fitted in the place of the lamp under the boiler. By this arrangement, and by means of some other precautions not necessary to be described here—since this book is not intended to explain the details of chemical manipulations—the hydrogen gas, brought out by the heat from the dried vines, with all the stored force contained in it, derived from its forcible separation from oxygen, and its prodigiously strong tendency to reunite with it so soon as it should have an opportunity, was conveyed under the boiler of the little steam-engine, and there allowed to come out into contact with the air, and, of course, with the oxygen which the air contained.

Still the hydrogen, notwithstanding this very strong tendency to unite with oxygen, for some mysterious reason can not do so while both are cool. While the hydrogen was in the gun-barrel, although it was very hot there, it did not combine with oxygen, for there was none there. All oxygen was, of course, entirely excluded from the interior of the barrel. And when the hydrogen issued from the pipe, and so came into contact with the oxygen of the outer air, it could not even then begin to combine, because it was not now any longer hot, having become cooled in passing through the tube. But if ever so small a portion of it could be heated to the right point, when it was in contact with the oxygen, the two would immediately combine with great force, and this force would appear in the form of heat, which would immediately act, too, in raising the portions of the gases next to it to the right temperature, and so the union would continue to go on with great energy as fast as the hydrogen issued from the mouth of the pipe.

Such is the philosophy of the burning of gas issuing from a tube.

The energy, in the form of heat, which is furnished by the reunion of the oxygen and hydrogen, separated previously by the action of the sun, is far greater than is necessary for carrying on the process of combustion. In the case of Lawrence's experiment, a great portion of the heat —that is, of the *force* in that form—passed up through the bottom of the boiler, and transferred itself to the water, converting it into steam. The steam, in its turn, delivered the force to the piston in the little cylinder, and this communicated it to the piston-rod, and this to the wheels and bands connected with the mechanism of the figures, and in a very short time all the little men were as busy at their work as if they had been alive.

"There!" said Lawrence, as his experiment arrived at this successful result; "see how I make the men work by the force I gathered from the sun by means of my peas and beans."

"It is not the peas and beans at all," said Rick; "it is your steam-engine."

"But where does the force come from to make the engine work?"

"It don't come from any where," said Rick. "All you have to do is to make a fire under the boiler. That's the way with all steam-engines."

Thus it appeared that, after all, Rick had not very clearly comprehended the principles which this experiment was intended to illustrate. But the lesson was not lost upon him by any means. The visible embodiment of the principle which the experiment presented to him remained pictured in his imagination for years. It gave him a *glimpse* of the truth at the time, and the memory of it aided him greatly in perceiving the full force and extent of it long years afterward.

It happened very frequently, in the various interviews which took place between Lawrence, John, and Rick, and in the conversations which Lawrence held with the two boys, that Rick very imperfectly comprehended what Lawrence explained, while John, whose mind was more mature in respect to the reception of general truths, understood them much more fully. For example, one day, when the three were returning from an excursion which they had been making together, they came to a place where an old man and his grandson were at work making hay. The old man had proposed that morning, at dinner, that he and Josie should go down and work a little upon the hay that afternoon.

"We can not do much," said he to himself, "for he is too young, and I am too old. But we can do something; and after every half hour of work we will take a little time for rest."

Just as Lawrence and his party came along, the two hay-makers had come to a recess, as Josie called it, and had just gone to sit down upon a log, near the field, to rest.

Now Lawrence had been explaining to Rick and John that very afternoon that all the strength that we exercise in the action of all our bodily organs, whether of the limbs or of the brain, is derived from the stored force laid up in the food which we take, and this force tends to expend itself in young animals through the organs of motion, leading them to take pleasure in all kinds of rapid bodily movement, while in the old a larger portion of it comes into action through the organs communicating more immediately with the mind. Now he and the two boys came by the

WE'RE RESTING.

place where the hay-makers had been working just at the time when the old man and Josie had gone to take their seat on the log.

Josie had asked his grandfather, just before they had sat down, whether it was not time for them to take a rest, for he said he was so tired he could not possibly do any more; and so they had sat down together on the log. But they had not been there more than two minutes before Josie, having recovered his breath a little, jumped up and began to climb the gnarled and misshapen old oak, under the shadow of which the log which his grandfather had taken for a seat was lying. His grandfather had remonstrated at first, asking him why he wanted to climb that tree. It would be a great deal better, he said, for him to sit still and rest. But Josie said that he was rested already, and so went on climbing. It was when he had reached a considerable height upon this tree that Lawrence and the two boys came along by a path on the other side of it.

"Hi-yo! Josie," said Rick, calling out to him, "what are you doing there?"

"We're resting," said Josie. "Grandfather and I have been making hay, and we're resting."

The truth is, that the supply of force introduced into the system in the food, while it must always reappear in some way, makes itself manifest in very different forms in the same system, and the proportions in which it appears in these different forms vary very much at different periods of life. A portion of it develops itself as heat, and is employed in keeping the body warm. Another portion is expended in giving strength to the muscles and limbs, and another still in maintaining the action of the vital organs, and even, as is now generally believed, those of the brain, through the instrumentality of which, in some mysterious way, the mind performs its functions. In childhood and youth the force expends itself, in most of these ways in a rapid and fitful manner, changing from one to another incessantly, the different limbs and organs becoming easily fatigued, and also being very soon and very easily restored by a brief period of repose. In age the action in all these modes is more steady and slow, and the change from one form of expenditure to another is much less frequently demanded.

So Josie, in the case referred to, had not remained five minutes upon the log before he felt rested, and the force within him had begun to accumulate and to demand fresh outlets through which to expend itself. It found these outlets in the exercise of his limbs in climbing the tree, and in those movements in his brain that were concerned in the curiosity which he felt in seeing whether there was a bird's nest or a squirrel's nest among the branches, or in the excitement and pleasure which the strange appearance of every thing beneath and around him would assume when viewed from his lofty position. In the mean time Lawrence and the two boys came to the place, and Lawrence, being acquainted with the old man, took a seat beside him on the log and began to talk with him about old times, and the old man soon became greatly interested in recalling and relating the incidents of his early youth, when all that part of the country was in so different a condition.

Josie soon came down from the tree, and stood for a moment listening to the conversation between Lawrence and his grandfather, but very soon he and Rick set off to run down toward a little brook which flowed near, and where, he said, he thought there were some fishes. Josie went dancing and capering backward along the path before Rick as if he had not done any work for a week.

John preferred to stay under the tree, and very soon he took a seat upon the log by the side of Lawrence. He sat there for a long time listening with Lawrence to the old man's stories.

When afterward, in continuing their walk, Lawrence explained to the boys that the force which sustained all the activity that they had observed in the two cases—that of the mind in the man, and of bodily motion in the boy—was derived from the effect of the food which they had taken, in bringing with it into their systems force stored in it by the sun, Rick said that, in respect to Josie, he did not believe it was any thing that he ate that made him act so, but only his love of fun!

CHAPTER XVI.

DETONATIONS AND EXPLOSIONS.

When a certain degree of force is very suddenly set free, there is often produced what we call a detonation or an explosion, using the one term or the other according to the quantity of force which is brought into action.

Thus the quantity of force produced by the sudden combustion or other chemical action taking place in the composition contained in a boy's torpedo, when thrown upon the pavement, is small, and we call the result a *detonation.* In the case of the powerful torpedoes inclosed in iron cases, and used for blowing up hostile ships at the entrance to a harbor, a precisely similar effect, and one produced, too, by similar means, though vastly more powerful, is called an *explosion.* The *noise* that is produced both by detonations and explosions is due altogether to the action of the liberated force upon the *air.* The sudden heat that is developed expands and drives back the air in all directions, and the sudden return of it produces a shock attended with a variety of concussions which sends abroad in every direction through the surrounding atmosphere that kind of confused medley of vibrations which in their effect upon the ear constitute what we call *noise.* If there were no air, the most tremendous explosion that can be conceived would produce no sound.

The most rapid mode by which force can be developed—that is, brought out from a latent into an active state—is by some kind of chemical action, usually *combustion*, which word, in fact, only denotes that kind and degree of chemical action which is so rapid as to be attended with the evolution of light and heat; but, even by this means, the force would not be ordinarily evolved with the degree of rapidity necessary to produce an explosion without another condition which will be hereafter explained.

The most effective substances in ordinary use to produce explosive force are gunpowder, gun-cotton, nitro-glycerine, dynamite, and the like, all of which act on substantially the same principle, namely, that of producing an extremely rapid combustion by bringing large quantities of oxygen on the one hand, and of carbon and hydrogen on the other, into close juxtaposition with each other, so that they may rapidly combine.

For one of the great fundamental facts in the economy of nature, as we observe it, is this: that far the greater portion of the action which we see taking place around us on this globe consists in the *energy* put forth by the sun in separating carbon and hydrogen from oxygen, and then, as the counterpart and correlative of this, the intense eagerness manifested between the oxygen, and the carbon, and hydrogen in coming together again.

Now the whole philosophy of the explosive force manifested by gunpowder and the other substances above named consists in their composition being such as to bring quantities of carbon and hydrogen on the one hand, and of oxygen on the other, into close juxtaposition, so that they may unite, and thus liberate and restore, as it were, the force that was expended in separating them, with the greatest rapidity.

To illustrate this, suppose we have a large and solid log of dry wood. Now the wood of such a log contains carbon and hydrogen, but no oxygen. The oxygen is in the air around it. When the substances are raised to the right temperature to bring their tendency to combine into action, the log begins to burn—that is, the oxygen combines with all that portion of the carbon and hydrogen which lies on the *surface of the log*, which is all that is accessible to it at first; and it can only gain access to the inner portions as fast as the outer ones are burned away.

If now the log is split up into small and slender portions, and, still more, if it is converted into shavings by a plane, the air—that is to say, the oxygen that is in it—gains a much more ready access to the substance of the wood, being able to introduce itself into the interstices of the heap of sticks or shavings, and the combustion will be greatly accelerated; and, consequently, the force that is developed, though it will be no greater in the total amount, will come forth from its latent into an active state in a much more rapid manner.

And if it were possible to reduce the wood to *dust* by a rasp or a saw, and then to keep the particles suspended in the air, and near enough to each other to furnish to each portion of carbon and hydrogen a portion of oxygen, neither more nor less than it required, close at hand, the whole mass would flash, as it were, into a flame with almost the suddenness of gunpowder.

Indeed, the dust of wood or of coal mingled thus with air is sometimes blown into furnaces, and is found to produce a wonderful effect, through the rapidity and the force of the combustion which results.

Now the oxygen in the air, being a gas, can not be kept mingled in this way with any powdered substance. If it could be obtained in a solid form, and could be pulverized, and in that form mingled intimately with any powdered compound of carbon and hydrogen, then, when a portion of the mass was raised to the right temperature, an almost instantaneous combination, accompanied with a sudden development of force in the form of heat, and having the effect of an explosion, would result.

But oxygen can not be made to exist by any means now known in a solid form, *except in combination with some other substance.* The best, therefore, that can be done is to use it in combination with some other substance for which it has the weakest possible affinity—that is, the one which will most easily and readily let go its hold, so as to allow the oxygen, with the least hinderance, to enter into combinations with the hydrogen and carbon. This substance is *nitrogen.*

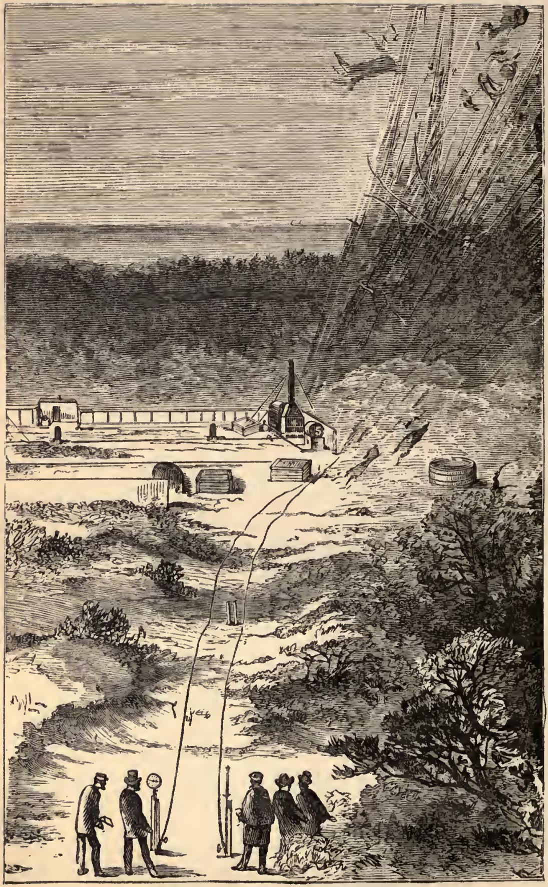
The great distinguishing characteristic of nitrogen is the weakness of its affinity for other substances, just as the strength of its affinity is the great characteristic of oxygen. Now nitrogen will combine with oxygen in various ways and in many different proportions, the two elements being at all times ready to let go at once their hold upon each other whenever any other substance is presented for which oxygen has a stronger attraction.

Nitrogen is usually described in books as one of the most *inert* substances in nature, and yet the compounds which it forms with other elements, and especially with oxygen, are the most violent in their action of all known substances. Nitric acid is perhaps the principal of these combinations, and is one of the most powerful and destructive agents that exist. It consists essentially of a large quantity of oxygen held in combination with a smaller quantity of nitrogen, united to it by a very feeble force. People are often surprised that a substance so inert should form compounds so active and violent; but, instead of its being a matter of surprise that this should be the case, it is the very inertness of this element on which the violence of the action of the compound depends—that is, it holds the oxygen committed to its keeping with so feeble a grasp, and releases it so readily, that this last immensely powerful agent is always at once set free, and enabled to act with its full force upon other substances. It is the oxygen which is really the agent in all the violent action which results, the nitrogen only serving the purpose of holding it weakly, and releasing it readily, when the time for action comes.

Still, however rapidly the process of combustion may be made to proceed by this arrangement—in the case, for example, of gunpowder—the force is not developed with sufficient suddenness and in sufficient quantity to produce all the effects of an explosion without being restrained and allowed to accumulate its energy. Thus an ounce of gunpowder, ignited in the open air, burns with a flash indeed, but the combustion of it requires a perceptible period of time, and the force developed has time to pass off into the air without any very sudden or violent action; but let the same quantity be inclosed in the cast-iron shell of a hand-grenade, or rammed into a gun-barrel, or into a hole drilled into a rock, and confined there with wadding or tamping, so that the force which results from the beginning of the burning, can be held in restraint until the combustion is completed, then, when it at last breaks away, and the whole accumulated force comes into action in a single instant, a very violent explosion is the result.

There are many other ways in which force, developed gradually, may be accumulated and allowed to act all at once so as to produce an explosion. The bursting of a steam-boiler is one example of this, and the accumulation of some mysterious force in the case of a volcano, until it acquires energy sufficient to burst the barriers that confine it, is another.

In the case of the steam-engine, the force gradually produced by the heat from the coal, acting upon the steam,



MEASURING THE BURSTING PRESSURE.

works itself off, when all is right, through the machinery; or, if there is any tendency to accumulation, the safety valve allows the surplus to escape. When, from any cause, the force accumulates too rapidly to pass off through these avenues, it increases in tension until it becomes sufficient to overcome the cohesive strength of the iron of the boiler, and an explosion is the result.

The precise degree of this tension may be exactly measured. It is obviously of the nature of a *pressure*, and it is measured and estimated sometimes by the number of pounds to the square inch, and sometimes by what are called *atmospheres*. The pressure of the atmosphere is about fifteen pounds to the square inch, so that a pressure of two, three, or ten atmospheres would be that of thirty, forty-five, or one hundred and fifty pounds to the square inch respectively. In locomotive engines, the pressure employed is often from fifty to sixty pounds to the square inch.

Great as the pressure is, in many cases, which acts upon the interior surface of a large boiler, it can be conveyed very easily, by small pipes, to a great distance, and there observed and measured safely. In this way some experiments were made during the last year, under the direction of the Navy Department of the United States, to ascertain certain points in respect to the amount of pressure realized in large boilers when raised to the bursting point. The experiments were made upon Sandy Hook, at a place far removed from any dwelling. The engraving shows the effect produced by one of the explosions.

In the middle distance is seen the inclosure where the boilers to be experimented upon were stored, and a representation of the result of one of the explosions. In the foreground is also the place where the observers were stationed. Pipes are seen lying upon the ground, and forming a communication between the boiler experimented upon and the station. These, being connected with the boiler at one end, and with the gauges at the station at the other end, afford the means of determining the pressure in the boiler at each different stage of the experiment. There were several boilers tested. In one of them, when the pressure reached fifty pounds to the inch, one of the interior braces gave way; and when, at length, the index of the gauge marked fifty-three pounds to the inch, the boiler burst with a terrific explosion, and portions of it, and of the shell connected with it, weighing about four tons, were hurled high into the air, and thrown to a distance of 500 feet from the inclosure.

The great violence of the effect, in cases like this, where force is held in restraint for a time after being brought into great tensile action, arises from its being *converted into heat* by the compression, the prevention of motion seeming to operate in some sense in the same way as the extinguishment of it. In the case of gunpowder, the gases produced by the combustion, of the carbon and sulphur, by means of the oxygen in the nitre, are found to occupy about 500 times the space occupied by the gunpowder itself. This is an enormous expansion; but if this expansion is prevented for a moment from taking effect by the resistance of the sides of the gun-barrel, or of rock, within which the combustion goes on, the gases become heated so as to demand 2500 *times* the original space; and this is the cause of the enormous increase in the violence of the effect produced by the combustion of such substances when it takes place under confinement. With some of the immense guns now manufactured by the English and American governments, balls weighing 500 pounds are thrown with such force as completely to penetrate a target consisting of a plate of solid iron *eight* inches thick, backed by *six* inches of the very hardest kind of wood, behind which is another plate of iron *five* inches thick, with another thickness of six inches of hard wood beyond it, and a one and a half inch plate of iron in the rear—the whole all firmly riveted together!

Besides gunpowder, there are various other explosive substances, such as gun-cotton, nitro-glycerine, dynamite, and others, the properties of which depend upon a constitution substantially the same in principle with that of gunpowder, namely, the combining of a substance consisting chiefly of carbon and hydrogen with some other substance containing a large quantity of oxygen in a state of concealment or disguise, as it were. In gunpowder, the combustible substances—the sulphur and carbon—are finely pulverized in a mill, as is also the nitre which contains the oxygen. In gun-cotton, on the other hand, nature divides the combustible material by forming the long, slender filaments of the cotton, and the oxygen is added by means of a combination of acids containing it, which infiltrates itself into the substance of the fibre, and thus brings the two elements into a much closer connection with each other than can possibly be effected by any mere mechanical means. It is substantially the same with nitro-glycerine, and with a composition called *dualin*, which are estimated to exert by their combustion *ten times* the force of gunpowder!

These, and perhaps most other explosive substances now used, depend for their effect on the very energetic manner in which oxygen, when held weakly by nitrogen, under certain conditions lets go its hold and seizes upon any carbon or hydrogen that is within its reach. And not only these, but a great many of the most remarkable phenomena of nature depend upon this relation which the action of nitrogen and that of oxygen have to each other. The reader should bear this principle distinctly in mind, namely,

That the counterpart of oxygen in the economy of nature, in respect to the strength of affinity for other substances, and its tenacity of hold when in combination with them, is *nitrogen.* Nitrogen is the great weak-holder. It is as remarkable for the feebleness of its tendency to unite with other substances, and the readiness with which it gives them up to other affinities, as oxygen is for the contrary qualities.

And a very large proportion of the processes going on all the time in the natural world, and of the phenomena of animal and vegetable life, are dependent upon the mutual play and interaction of these two elements in relation to themselves and to other substances, as determined by the weak affinities of the one, and the strong affinities of the other.

Thus, as we saw in the preceding chapter, the forcible separation of oxygen from its strong combinations, by the power of the sun, in the leaves of plants, and the delivery of it to the weak custody of nitrogen, and, finally, the surrendering of it back, under new circumstances, to its strong combinations again, is the secret of a very large portion of the phenomena of vegetable and animal life. It is in accordance with this view that *plants* have comparatively little need of air, and that chiefly for the sake of the *carbon* which the air contains; but *animals* have great need of it, on account of the *oxygen* which they use for the sake of the heat-force which they obtain by letting it fall into combination with the carbon again.

Some persons are, at first thought, surprised that, since this is the state of the case—that is, since oxygen has so strong an affinity for other substances, and as so large a quantity of it is held in the air, and in a peculiarly weak union with nitrogen—for the air is chiefly composed of those two elements—that the action of the air is not more instantaneous and violent than it is. The explanation is, that the oxygen in the air can not act with very great rapidity or energy on account of the wide diffusion and extreme dilution of it. The proportion in the atmosphere is only about one quarter of its bulk, and the substance of it is so minutely divided and so much diffused that the intensity of its action is greatly diminished in consequence of the limited supply of it which any given current of air can bring into action in any given time.

There are many other examples of chemical action so energetic as to produce detonations and explosions, the effect of which is dependent upon the powerful attraction of certain other substances possessing in some degree the characteristics of oxygen. There are also certain metals that have so ardent an affinity for oxygen that they seize it with even greater avidity than that which is manifested by the action of carbon or hydrogen upon it. They seize it wherever they find it, no matter how strong its existing combination may be. Two very conspicuous examples of these are the metals *potassium* and *sodium*—the bases respectively of potash and soda. These metals have so excessively strong an affinity for oxygen that they decompose water to obtain it; and they can not be retained in a metallic state without very special and effectual precautions to protect it from the water existing in the atmosphere, and in almost all substances around them.

And the action, moreover, is so violent that all the phenomena of combustion are produced when they are brought into contact with water. It is very wonderful to see a globule of either of these metals burst into a blaze when thrown into water, or placed on a wet surface of any kind.

The great heat developed by this intense action is made use of to produce explosive effects by arranging the materials in such a way as to allow them suddenly to combine in any confined space. This has been tried especially with *sodium*, by inclosing a portion of it, and also a portion of water, in two glass tubes connected together by a narrow neck or division, somewhat like that of an hourglass. This neck is closed by a division formed of some substance soluble in water, such as sugar, or salt, or a film of gum, or glue. The charge, thus prepared, is placed, for example, in the hole drilled in a rock, and closely confined there by a wadding or tamping rammed in. After the lapse of a certain time, which can be calculated with some accuracy beforehand, the dividing substance is dissolved by the water which is in contact with it on one side, and the water and the sodium rush together. The water is decomposed. The oxygen of it combines with the sodium and forms soda. The other element of the water—that is, the hydrogen, is set free in the form of a gas, and is so intensely heated by the energy of the chemical action that an explosive force is generated sufficient to rend the rock in pieces.

Thus the philosophy of detonations and explosions is, in general, simply this, namely, that substances having a very powerful tendency to combine are brought together under such conditions that this tendency may be suddenly set free to act; then the particles of which the substances are composed fall together, as it were, with enormous force, though it is a force acting through very minute distances as estimated by our senses. In thus falling, and by the sudden arrest of the force with which they fall, they generate very intense heat, and this heat, acting through the gases which are likewise usually also set free by the action, develop an enormous expansive force, which, suddenly breaking loose from the restraints confining it, produces the disruptive effect, while the shock communicated to the air produces the sound; these together constitute the explosion.

CHAPTER XVII.

FORCE IN RELATION TO TIME.

THERE are some very interesting and important considerations involved in the relation between time and force—considerations which are necessary to be taken into account in order to the attainment of clear and correct ideas of the fundamental principles involved in the subject.

In estimating absolute quantities of force, the element of time is not necessarily to be taken into account at all, though at first thought people are generally apt to imagine it otherwise. But the amount of force expended in raising one pound one foot is an absolute and definite quantity, whether more or less time is expended in producing it.

A gallon of water is the same quantity whether it falls drop by drop and is half a day in accumulating, or flows in a gushing stream so as to fill the measure in a minute. In the same manner a foot-pound is a foot-pound, neither more nor less, whether it is the work of a squirrel raising the pound slowly and laboriously by a cord wound round an axle connected with his revolving cage, or is a part of the immense energy expended in raising, in five seconds, by steam, a trip-hammer weighing many tons.

When we say that a horse is five or seven times stronger than a man, we mean that he can exert a force in *one hour* equal to that which a man can exert in *five or seven* hours. The theoretical horse-power—that by which the efficiency of powerful engines is estimated—is 33,000 foot-pounds per minute;* but every one of those foot-pounds represents a quantity of force precisely equal to that exerted by the squirrel in raising a pound weight one foot, or an ounce weight sixteen feet, or, if we can imagine such a thing, that exerted by a flea trained to work in a mimic treadmill, and raising thereby a weight of *one grain* as many feet as there are grains in a pound.

Thus, in simply estimating quantities of force, the element of time is not at all concerned, just as in estimating any absolute quantity of water we have nothing to do with the time that was required for it to flow through a particular faucet; but in estimating the amount of force which can be obtained from particular sources of power, we have to consider the element of *time*, in order to determine the effectual value of the results. Just as in the case of water, though a gallon is a gallon, neither more nor less, however slowly or rapidly it may come, we have to consider how many gallons a given source will supply *in a given time*, in order to make our calculations correctly in respect to what can be done with it.

There are two respects in which the element of time comes into the account in calculations relating to the employment of force. First, the rapidity with which the force is either brought into action from its latent state, or can be delivered to the control of man; and, secondly, the rapidity with which it can be transmitted from place to place. In respect to the first point, in the burning of coal under the boiler of a steam-engine, force is developed by coming from a latent into an active state; and in the case of a millwheel carried by a stream of water, the force is already in action, but is delivered, or, rather, a portion of it is deliv-

---

* This would be about what he would do by walking off at the rate of one step two feet long for every second, and raising by means of a rope passing over pulleys a weight of 270 pounds.

ered through the mill-wheel to the control of man. It is, of course, important to consider how much force such sources of supply would furnish in a given time.

And, secondly, if the force so furnished is to be transmitted from one place to another, either by water-pipes, or air-pipes, or wires, or bands, it is often necessary to consider the time which will be required for such transmission.

It is surprising how great a difference there is in the rapidity with which force, in its various forms and through different media, can be transmitted. We have a good illustration of this in the case of the eruptions of Vesuvius which are taking place on so remarkable a scale at the time of this present writing. Let us see at what different rates of speed the forces that are set in motion by any one of the explosions that take place are transmitted to different distances from the spot. First, if we suppose the distance from the crater to Naples through the air is ten miles, a *bird*, frightened by the thundering report and the burst of vapor and flame, would fly to the city in ten minutes, the *sound* of the explosion would traverse the intervening air in perhaps a minute and a half, and the *light* of the flash in about $\frac{1}{19,200}$ of one second, a speed that is altogether inconceivable to us.

And yet all these different modes of communication are only examples of the *transmission of force* in different forms, the first impulse being given in each case by the explosion.

It is impossible for us to form any conception of the velocity of such a motion as that of light, nor picture to our imagination any kind of undulation as moving at such a rate.

We can, however, gain some idea of the *nature* of such a motion by attempting to form some definite conception of the manner in which motion must pass through any elastic substance. Suppose, for instance, we have a long elastic cord or line, like an India-rubber tube, except that its being hollow would be of no consequence, and that two persons are experimenting with it, one having hold of each end. Now if the person at one end gives a sudden pull, the motion will be communicated from that end to the other in this way, as is supposed, namely, the particles of the India-rubber next the person's hand that pulls will, by their attraction for those next beyond, draw them in the direction in which they themselves have been pulled, and they the next, and so on by a kind of wave or *undulation of motion* from one end of the line to the other.

It would be substantially the same in the case of pushing, provided that the line could be prevented from bending laterally.

It is supposed that the motion is communicated in a somewhat similar way, only with inconceivably greater rapidity, in the case of a pull or a push communicated through an iron wire, or through any other solid substance—that is, that one set of particles communicates its motion to the next, and the second set to the third, and so on to the end; and, of course, that all such transmissions of motion require a certain portion of time, however minute, and that the period required is in proportion to the distance passed over.

The reader will perceive, on a moment's reflection, that undulations or vibrations of this kind are very different from those of waves in water, in this respect, namely, that the direction of the motion of the particles is backward and forward instead of being upward and downward. There is, however, a striking analogy between the two different modes.

If this is the true theory of the transmission of the solar radiation, for example, we may well be amazed at the inconceivable capabilities of nature in respect to the phenomena of force. The distance from the earth to the sun is so great that it would require 300 years for a railroad train at full speed to traverse it, and yet the undulations of light pass over it in eight minutes and a half.

And then, on the other hand, the magnitude of the distances that the human mind has to take cognizance of in the visible universe is not less amazing than the rapidity of the action taking place in it; for, though light would pass in less than ten minutes from the sun to the earth, there are stars known to be so remote that it would require something like a thousand years for the light coming from them to reach us when proceeding at the same rate of motion—that is, at a rate which would traverse a distance *in about eight minutes* which it would take a railroad train 300 *years* to pass over, though going at full speed.

Electricity, as it manifests itself in passing along the telegraph wire, is supposed to be a force in process of being transmitted in the form of some kind of vibratory or undulatory motion, either of the substance of the wire itself, or of some subtle medium contained in it. This is inferred from the fact that a certain amount of force in some form or other must be expended at one end of the wire, and the same amount in some other form is, or may be, developed from it at the other end. The force thus necessary at the beginning is usually generated by a process something like combustion, in which zinc, or some other metal, takes the place of fuel; that is to say, the process is like combustion in the fact that it consists of a powerful recombination of the metal with oxygen previously separated from it, only the combination takes place under such circumstances that the liberated force reappears in the form of electricity instead of in that of light and heat.

But there must always be an expenditure of force in *some* form to set the electric current in motion. This force, as has already been said, is supplied generally by a battery at one end of the line; but when a special current has to be sent from any intermediate point, for any special purpose, a new force must be imparted by an apparatus for consuming an additional quantity of zinc fuel, if it may be so called. The engraving represents the manner in which this is done, or was formerly done, in some countries in Europe. An accident has happened to the train, and the official wishes to communicate the knowledge of the fact to the next station. He has in his hand a small battery inclosed in a box. By a slight movement of the handle he sets the battery in action. The oxygen begins to combine with the zinc, thus restoring, as it were, the force with which the two elements were originally separated from each other. This force appears in the form of electricity, and the man, by means of a conductor attached to a long, slender pole, communicates the force to one of the wires, and thus can send a series of impulses to the nearest station.

He can not communicate a message of *words* conveniently in this way, but he can call attention and procure help somewhat as a person sick in a chamber can call for help by knocking on the floor under circumstances in which he would not be able to communicate any information in words.

This method, however, is now seldom used on any railroad, other more convenient ones having superseded it; but it will illustrate the principle which I have been explaining.

The word force is used in several very different senses in common parlance. The import of the word, for example, is very different as used in the phrases force of gravitation, force of cohesion, and other similar expressions, from that which is implied when we speak of the force of a current

TRANSMITTING AN IMPULSE OF FORCE.

of water or of wind. Indeed, some writers have maintained that, on account of this ambiguity, the word force ought to be banished from all scientific discussions, and the word *energy* substituted, to denote that form of force which communicates itself in some kind of motion from one body to another, and expends itself in the one just in proportion as it passes into the other. It is force in this sense which has been chiefly treated of in this volume—that is, force in the sense of *energy*, which is diminished in one body just in proportion as it is imparted to another.

And the portion, too, it must be remembered, which is lost by one is precisely that which is gained by the other. Let a log be rolled from the bank of a river into the water, and the flow of the current will soon set it in motion down the stream; but just so far as motion is imparted to the log, just to that precise degree that of the water that impinges upon it is diminished; that is, the motion of the water is retarded just as much as the log is impelled, so that the whole amount of motion is the same as before.

And, in the same manner, a vessel at sea is driven forward only so fast as the wind itself is kept back by it; that is, the wind can not give up its energy and keep it too. This is true in cases of oblique as well as of direct action, as, for example, in the case of a windmill, or a vessel sailing *on a wind*, as they say, in which cases the wind strikes the sails obliquely, and moves them forward by an indirect reaction.

It is only just so far as the wind itself, or a portion of it, is retarded in its motion in one direction that the vessels are made to move in another; that is, the force or energy is not *produced;* it is only parted with by one body to be received by another.

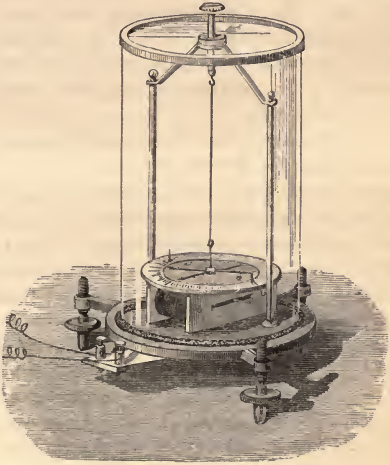
It is thus only a small part of the moving force or energy that man withholds from the wind by the sails of his ships, or of his windmills by his sails, or from the current of a

OBLIQUE ACTION.

river by his water-wheels. Perhaps the greatest force that man has wholly under his control is that drawn from coal, and kept under subjection and guidance in the large steam-engines that he builds. The British government have recently constructed some war steamers of a very large class, one of which, the Devastation, has engines of 5600 horse power. Think of a team of horses four abreast, and more than two miles long—for that would be about the space that such a power represented by horses would require—and all entirely under the perfect control and management of one man, so that it can be made to obey orders communicated by the slightest signals of the officer of the deck—

signals made by the motion of the fingers of his hand to "Ease her," "Back her," "Stop her," and the like—with the promptness, and, at the same time, with the self-restraint of the most docile dog; and then again, at the word, or, rather, the touch of command, can be made to urge the mighty mass of the ship, with its immense weight of iron plating, and its enormous guns, and its hundreds of working population, against the strongest gales and through the heaviest surges with irresistible energy.

On the other hand, the smallest forces which man takes definite cognizance of and measures are perhaps those developed by the faintest currents of electricity. The instrument by which such feeble forces are measured is called the Torsion Balance.



THE TORSION BALANCE.

It is called the Torsion Balance because the force with which that of the current is brought into comparison is the resistance to the torsion or twisting of some very delicate fibre, usually a single filament of a spider's or a silk-worm's spinning. The engraving shows the form and general appearance of the instrument. It is inclosed in glass, to protect the needle within from currents of air. It stands on a tripod furnished with screws to secure a perfectly level position for it. The current of electricity is brought by one of the wires on the left, and carried away by the other. The receiving wire, after entering beneath the instrument, is wound round a coil, a portion of which is visible in the engraving. By this means the magnetic effect which such a current is capable of producing is greatly increased. This magnetic influence, acting, through the circular plate above it, upon the needle suspended by the filament, causes it to turn in one direction or the other, its turning being resisted by the torsion of the filament, and the degree of it, as marked by the gradation of the circle, denoting the strength of the current.

By this instrument forces inconceivably minute may be measured and compared.

The doctrine that lies at the foundation of the science of force—that, namely, which it has been the main object of this book to explain and illustrate, is this: that no force, in the sense of energy, can ever be *generated*, but can only, when already existing, either in an active or suspended form, be transmitted or released, each particular movement of it requiring a certain lapse of time. The cases which seem at first view to be exceptions to this principle are all illusory, as, for example, that of the explosion of a blast of gunpowder rending rocks in pieces by the communication of a very small force through an electric wire. Here the great force which the small one seems to produce is not *generated*, but only *called out into action.* The true source of the disrupting power is in the sun, which separated the oxygen from the carbon by the actinic force of its rays when the wood which furnished the carbon for the gunpowder was growing. The carbon and the oxygen being placed side by side in the gunpowder, with an immensely strong tendency to come together—which tendency can, however, for some mysterious reason, only come into action when a portion of them is raised to the right temperature—the spark produced by the electric discharge acts, not to *generate* the force, but only to *release it from its suspense and detention.* It is in principle a case precisely analogous to that of a child who sets to falling a long row of bricks by a touch upon one of them at the end. The whole amount of force with which the bricks fall is very great compared with that of the touch with which the whole movement was begun; but it is force which was *accumulated in the bricks*, as it were, by the labor of the child in setting them up one by one—in lifting each one up far enough to set it on the end. Thus the force with which the bricks fell was only an *accumulated force released*, and not a new force generated by the slight touch which set the train in motion.

And just as in the movement transmitted through such a train a *certain time* is required for the movement to pass onward to the end of it, so in all cases a definite lapse of time is expended in every mode by which force is transmitted—sound passing through the air requiring but little, electricity through a wire very much less, and light through the luminiferous ether, which is supposed to be the medium that conveys it, the least of all.

CHAPTER XVIII.

CONCLUSION.

THE concluding limit of the space within which the discussion of each subject in these volumes is necessarily confined now draws near, and warns me that I must bring what I have to say upon Force to a close. This is not, however, because the subject is exhausted. All that has been said in this volume, and, indeed, all that man has yet learned, and, in fact, all that is possible, in this state of being, for him to know, forms but the merest beginning of knowledge in this boundless field. Every young man who reads this book attentively will find that he knows less, not than he actually did know, but than he imagined that he knew before he began it; for the field of knowledge on this subject is unbounded. The färther we enter into it, the wider the region beyond us expands, but then the stronger becomes our desire to go on and explore the mysteries that remain, so that the effect of such incipient studies as these is to discourage self-conceit, not weary out the love of knowledge.

It almost always surprises the learner when he is first informed that the subject of force really includes almost, if not all the phenomena of nature that are subject to our cognizance. But this is strictly true, for every thing that takes place is a manifestation of force of some kind, except, perhaps, the phenomena involved in mental operations. Many scientific men would not even except those, on the ground that even mental operations, so far as they manifest themselves to the human observation, whether they are our own or those of others, act through and by means of *bodily organs*, which in all their actions are dependent entirely on some form of material force communicated to the system in the food.

However this may be, it is certain that all which takes place in the visible universe around us consists of movement of some kind, *produced by some previous movement*, and thus forming a part of the grand circuit which the vast amount of cosmical force—that is, the force that is in action in the universe, constantly describes.

Besides this moving and acting force called *energy*, which expends itself, or rather transmits itself in its action, there is what is sometimes called a force, namely, *pressure*, which, so long as it produces no motion, undergoes no change. For example, if a heavy weight is supported in the air on the top of a tall pillar of wood, like a mast, and remains at rest, it will continue to exert the same pressure upon the fibres of the wood forever without any change. So long as there is no movement there is no expenditure, and the pressure remains undiminished. But if the pillar be suddenly removed, the weight begins to descend, passing through space and occupying time; and the force begins to be expended—that is, transmitted to the surrounding objects which it meets on its way, or encounters at the end of its descent. It is this force, acting *in time* and *through distance*, which is called *energy*, and has been the main subject of discussion in this volume.

Lawrence explained all these things pretty clearly and fully to John in his various conversations with him, and somewhat more in detail than they have been stated here. He also, from time to time, stated and explained particular facts to Rick, as he had occasion to see him, but without much attempt to make him understand abstract principles or extended generalizations. Such a boy must be taught *particulars* in respect to the phenomena of nature for a long time before he is prepared to see the *analogies* which connect them together, or to comprehend the general principles that underlie them all. Lawrence had too much knowledge of the nature and movements of a mind like Rick's, which is in process of formation, to attempt too much with it, so he was satisfied with calling Rick's attention to such points as could be made obvious through the senses. A boy of his age can much more easily understand, and will much more fully appreciate what he can see, or picture to his imagination in the form of a visible phenomenon, than things which exist in his mind only as a thought.

But the great effect produced on Rick's mind by Lawrence's instructions was, after all, a moral one—that is, it was the influence of them upon his feelings and affections. While he hated most of the teachers under whose care he had been successively placed—teachers who took apparently no notice when he did right, but scolded or whipped him when he did wrong—he soon began to form a strong attachment for Lawrence, whom he readily learned to consider as his friend; and though it is true that the knowledge which he obtained was comparatively slight, and of course, like the beginnings of all knowledge, was very superficial, still what there was of it was *knowledge;* and, what was better than all, it was knowledge acquired with pleasure, and was the beginning of a change in him, which, if it should be followed by measures and treatment of a similar character by the teachers of the Morningside School, would probably, in time, make him a good and happy boy.

There never was a more false or unphilosophical sentiment expressed than that conveyed by Pope's celebrated distich,

"A little learning is a dangerous thing;
Drink deep, or taste not the Pierian spring."

If such a doctrine were believed and obeyed, it would put an effectual stop to all acquisition of knowledge, for it is only a "little learning" on any conceivable subject that it is possible for any one in the present condition of the human mind to attain. We must learn *all we can*, be it little or a great deal, on every subject that comes within our view. We may, indeed, make a choice among the different subjects which lie open before us in regard to the degree of time and attention which we will devote to each, but no knowledge is useless simply because it is but a beginning.

There are thus two lessons taught by this book, or, rather, two truths to be learned from it:

First, that physical force is a very curious and interesting subject of study; and,

Secondly, that it may be made one excellent means of changing the heart and the character of a bad boy; but that the way to employ it for this end is to make it a subject of curious study for his mind, and not by the personal application of it to his body.

THE END.

VALUABLE AND INTERESTING WORKS

FOR

PUBLIC & PRIVATE LIBRARIES,

Published by HARPER & BROTHERS, New York.

☞ *For a full List of Books suitable for Libraries published by* Harper & Brothers, *see* Harper's Catalogue, *which may be had gratuitously on application to the publishers personally, or by letter enclosing Ten Cents in postage stamps.*

☞ Harper & Brothers *will send their publications by mail, postage prepaid, on receipt of the price.*

MACAULAY'S ENGLAND. The History of England from the Accession of James II. By Thomas Babington Macaulay. New Edition, from New Electrotype Plates. 5 vols., in a Box, 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $10 00; Sheep, $12 50; Half Calf, $21 25. Sold only in Sets. Cheap Edition, 5 vols., 12mo, Cloth, $2 50.

MACAULAY'S MISCELLANEOUS WORKS. The Miscellaneous Works of Lord Macaulay. From New Electrotype Plates. 5 vols., in a Box, 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $10 00; Sheep, $12 50; Half Calf, $21 25. Sold only in Sets.

HUME'S ENGLAND. History of England, from the Invasion of Julius Cæsar to the Abdication of James II., 1688. By David Hume. New and Elegant Library Edition, from New Electrotype Plates. 6 vols., in a Box, 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $12 00; Sheep, $15 00; Half Calf, $25 50. Sold only in Sets. Popular Edition, 6 vols., in a Box, 12mo, Cloth, $3 00.

GIBBON'S ROME. The History of the Decline and Fall of the Roman Empire. By Edward Gibbon. With Notes by Dean Milman, M. Guizot, and Dr. William Smith. New Edition, from New Electrotype Plates. 6 vols., 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $12 00; Sheep, $15 00; Half Calf, $25 50. Sold only in Sets. Popular Edition, 6 vols., in a Box, 12mo, Cloth, $3 00; Sheep, $6 00.

GOLDSMITH'S WORKS. The Works of Oliver Goldsmith. Edited by Peter Cunningham, F.S.A. From New Electrotype Plates. 4 vols., 8vo, Cloth, Paper Labels, Uncut Edges and Gilt Tops, $8 00; Sheep, $10 00; Half Calf, $17 00.

MOTLEY'S LETTERS. The Correspondence of John Lothrop Motley, D.C.L., Author of "The United Netherlands," "John of Barneveld," "The Rise of the Dutch Republic," etc. Edited by George William Curtis. With Portrait. Two Volumes, 8vo, Cloth, $7 00.

MOTLEY'S DUTCH REPUBLIC. The Rise of the Dutch Republic. A History. By John Lothrop Motley, LL.D., D.C.L. With a Portrait of William of Orange. Cheap Edition, 3 vols., in a Box. 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $6 00; Sheep, $7 50; Half Calf, $12 75. Sold only in Sets. Library Edition, 3 vols., 8vo, Cloth, $10 50.

MOTLEY'S UNITED NETHERLANDS. History of the United Netherlands: From the Death of William the Silent to the Twelve Years' Truce — 1584–1609. With a full View of the English-Dutch Struggle against Spain, and of the Origin and Destruction of the Spanish Armada. By John Lothrop Motley, LL.D., D.C.L. Portraits. Cheap Edition, 4 vols., in a Box, 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $8 00; Sheep, $10 00; Half Calf, $17 00. Sold only in Sets. Original Library Edition, 4 vols., 8vo, Cloth, $14 00.

MOTLEY'S JOHN OF BARNEVELD. The Life and Death of John of Barneveld, Advocate of Holland. With a View of the Primary Causes and Movements of the "Thirty Years' War." By John Lothrop Motley, LL.D., D.C.L. Illustrated. Cheap Edition, 2 vols., in a Box, 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $4 00; Sheep, $5 00; Half Calf, $8 50. Sold only in Sets. Original Library Edition, 2 vols., 8vo, Cloth, $7 00.

HILDRETH'S UNITED STATES. History of the United States. First Series: From the Discovery of the Continent to the Organization of the Government under the Federal Constitution. Second Series: From the Adoption of the Federal Constitution to the End of the Sixteenth Congress. By Richard Hildreth. Popular Edition, 6 vols., in a Box, 8vo, Cloth, with Paper Labels, Uncut Edges and Gilt Tops, $12 00: Sheep, $15 00; Half Calf, $25 50. Sold only in Sets.

STORMONTH'S ENGLISH DICTIONARY. A Dictionary of the English Language, Pronouncing, Etymological, and Explanatory: embracing Scientific and other Terms, Numerous Familiar Terms, and a Copious Selection of Old English Words. By the Rev. JAMES STORMONTH. The Pronunciation Revised by the Rev. P. H. PHELP, M.A. Imperial 8vo, Cloth, $6 00; Half Roan, $7 00; Full Sheep, $7 50. (New Edition.)

PARTON'S CARICATURE. Caricature and Other Comic Art, in All Times and Many Lands. By JAMES PARTON. 203 Illustrations. 8vo, Cloth, Uncut Edges and Gilt Tops, $5 00; Half Calf, $7 25.

DU CHAILLU'S LAND OF THE MIDNIGHT SUN. Summer and Winter Journeys in Sweden, Norway, Lapland, and Northern Finland. By PAUL B. DU CHAILLU. Illustrated. 2 vols., 8vo, Cloth, $7 50; Half Calf, $12 00.

LOSSING'S CYCLOPÆDIA OF UNITED STATES HISTORY. From the Aboriginal Period to 1876. By B. J. LOSSING, LL.D. Illustrated by 2 Steel Portraits and over 1000 Engravings. 2 vols., Royal 8vo, Cloth, $10 00; Sheep, $12 00; Half Morocco, $15 00. (*Sold by Subscription only.*)

LOSSING'S FIELD-BOOK OF THE REVOLUTION. Pictorial Field-Book of the Revolution; or, Illustrations by Pen and Pencil of the History, Biography, Scenery, Relics, and Traditions of the War for Independence. By BENSON J. LOSSING. 2 vols., 8vo, Cloth, $14 00; Sheep or Roan, $15 00; Half Calf, $18 00.

LOSSING'S FIELD-BOOK OF THE WAR OF 1812. Pictorial Field-Book of the War of 1812; or, Illustrations by Pen and Pencil of the History, Biography, Scenery, Relics, and Traditions of the last War for American Independence. By BENSON J. LOSSING. With several hundred Engravings. 1088 pages, 8vo, Cloth, $7 00; Sheep or Roan, $8 50; Half Calf, $10 00.

MÜLLER'S POLITICAL HISTORY OF RECENT TIMES (1816–1875). With Special Reference to Germany. By WILLIAM MÜLLER. Translated, with an Appendix covering the Period from 1876 to 1881, by the Rev. JOHN P. PETERS, Ph.D. 12mo, Cloth, $3 00.

TREVELYAN'S LIFE OF MACAULAY. The Life and Letters of Lord Macaulay. By his Nephew, G. Otto Trevelyan, M.P. With Portrait on Steel. 2 vols., 8vo, Cloth, Uncut Edges and Gilt Tops, $5 00; Sheep, $6 00; Half Calf, $9 50. Popular Edition, 2 vols. in one, 12mo, Cloth, $1 75.

TREVELYAN'S LIFE OF FOX. The Early History of Charles James Fox. By George Otto Trevelyan. 8vo, Cloth, Uncut Edges and Gilt Tops, $2 50; Half Calf, $4 75.

WRITINGS AND SPEECHES OF SAMUEL J. TILDEN. Edited by John Bigelow. 2 vols., 8vo, Cloth, Gilt Tops and Uncut Edges, $6 00 per set.

GENERAL DIX'S MEMOIRS. Memoirs of John Adams Dix. Compiled by his Son, Morgan Dix. With Five Steel-plate Portraits. 2 vols., 8vo, Cloth, Gilt Tops and Uncut Edges, $5 00.

HUNT'S MEMOIR OF MRS. LIVINGSTON. A Memoir of Mrs. Edward Livingston. With Letters hitherto Unpublished. By Louise Livingston Hunt. 12mo, Cloth, $1 25.

GEORGE ELIOT'S LIFE. George Eliot's Life, Related in her Letters and Journals. Arranged and Edited by her Husband, J. W. Cross. Portraits and Illustrations. In Three Volumes. 12mo, Cloth, $3 75. New Edition, with Fresh Matter. (Uniform with "Harper's Library Edition" of George Eliot's Works.)

PEARS'S FALL OF CONSTANTINOPLE. The Fall of Constantinople. Being the Story of the Fourth Crusade. By Edwin Pears, LL.B. 8vo, Cloth, $2 50.

RANKE'S UNIVERSAL HISTORY. The Oldest Historical Group of Nations and the Greeks. By Leopold von Ranke. Edited by G. W. Prothero, Fellow and Tutor of King's College, Cambridge. Vol. I. 8vo, Cloth, $2 50.

LIFE AND TIMES OF THE REV. SYDNEY SMITH. A Sketch of the Life and Times of the Rev. Sydney Smith. Based on Family Documents and the Recollections of Personal Friends. By Stuart J. Reid. With Steel-plate Portrait and Illustrations. 8vo, Cloth, $3 00.

STANLEY'S THROUGH THE DARK CONTINENT. Through the Dark Continent; or, The Sources of the Nile, Around the Great Lakes of Equatorial Africa, and Down the Livingstone River to the Atlantic Ocean. 149 Illustrations and 10 Maps. By H. M. STANLEY. 2 vols., 8vo, Cloth, $10 00; Sheep, $12 00; Half Morocco, $15 00.

STANLEY'S CONGO. The Congo and the Founding of its Free State, a Story of Work and Exploration. With over One Hundred Full-page and smaller Illustrations, Two Large Maps, and several smaller ones. By H. M. STANLEY. 2 vols., 8vo, Cloth, $10 00; Sheep, $12 00; Half Morocco, $15 00.

GREEN'S ENGLISH PEOPLE. History of the English People. By JOHN RICHARD GREEN, M.A. With Maps. 4 vols., 8vo, Cloth, $10 00; Sheep, $12 00; Half Calf, $19 00.

GREEN'S MAKING OF ENGLAND. The Making of England. By JOHN RICHARD GREEN. With Maps. 8vo, Cloth, $2 50; Sheep, $3 00; Half Calf, $3 75.

GREEN'S CONQUEST OF ENGLAND. The Conquest of England. By JOHN RICHARD GREEN. With Maps. 8vo, Cloth, $2 50; Sheep, $3 00; Half Calf, $3 75.

BAKER'S ISMAÏLIA: a Narrative of the Expedition to Central Africa for the Suppression of the Slave-trade, organized by Ismaïl, Khedive of Egypt. By Sir SAMUEL W. BAKER. With Maps, Portraits, and Illustrations. 8vo, Cloth, $5 00; Half Calf, $7 25.

ENGLISH MEN OF LETTERS. Edited by JOHN MORLEY.

The following volumes are now ready. Others will follow:

JOHNSON. By L. Stephen.—GIBBON. By J. C. Morison.—SCOTT. By R. H. Hutton.—SHELLEY. By J. A. Symonds.—GOLDSMITH. By W. Black.—HUME. By Professor Huxley.—DEFOE. By W. Minto.—BURNS. By Principal Shairp.—SPENSER. By R. W. Church.—THACKERAY. By A. Trollope.—BURKE. By J. Morley.—MILTON. By M. Pattison.—SOUTHEY. By E. Dowden.—CHAUCER. By A. W. Ward.—BUNYAN. By J. A. Froude.—COWPER. By G. Smith.—POPE. By L. Stephen.—BYRON. By J. Nichols.—LOCKE. By T. Fowler.—WORDSWORTH. By F. W. H. Myers.—HAWTHORNE. By Henry James, Jr.—DRYDEN. By G. Saintsbury.—LANDOR. By S. Colvin.—DE QUINCEY. By D. Masson.—LAMB. By A. Ainger.—BENTLEY. By R. C. Jebb.—DICKENS. By A. W. Ward.—GRAY. By E. W. Gosse.—SWIFT. By L. Stephen.—STERNE. By H. D. Traill.—MACAULAY. By J. C. Morison.—FIELDING. By A. Dobson.—SHERIDAN. By Mrs. Oliphant.—ADDISON. By W. J. Courthope.—BACON. By R. W. Church.—COLERIDGE. By H. D. Traill.—SIR PHILIP SIDNEY. By J. A. Symonds.—KEATS. By S. Colvin. 12mo, Cloth, 75 cents per volume.

POPULAR EDITION. 36 volumes in 12, $12 00.

COLERIDGE'S WORKS. The Complete Works of Samuel Taylor Coleridge. With an Introductory Essay upon his Philosophical and Theological Opinions. Edited by Professor W. G. T. Shedd. With Steel Portrait, and an Index. 7 vols., 12mo, Cloth, $2 00 per volume; $12 00 per set; Half Calf, $24 25.

REBER'S MEDIÆVAL ART. History of Mediæval Art. By Dr. Franz von Reber. Translated and Augmented by Joseph Thacher Clarke. With 422 Illustrations, and a Glossary of Technical Terms. 8vo, Cloth, $5 00.

REBER'S HISTORY OF ANCIENT ART. History of Ancient Art. By Dr. Franz von Reber. Revised by the Author. Translated and Augmented by Joseph Thacher Clarke. With 310 Illustrations and a Glossary of Technical Terms. 8vo, Cloth, $3 50.

NEWCOMB'S ASTRONOMY. Popular Astronomy. By Simon Newcomb, LL.D. With 112 Engravings, and 5 Maps of the Stars. 8vo, Cloth, $2 50; School Edition, 12mo, Cloth, $1 30.

DAVIS'S INTERNATIONAL LAW. Outlines of International Law, with an Account of its Origin and Sources, and of its Historical Development. By Geo. B. Davis, U.S.A., Assistant Professor of Law at the United States Military Academy. Crown 8vo, Cloth, $2 00.

CESNOLA'S CYPRUS. Cyprus: its Ancient Cities, Tombs, and Temples. A Narrative of Researches and Excavations during Ten Years' Residence in that Island. By L. P. di Cesnola. With Portrait, Maps, and 400 Illustrations. 8vo, Cloth, Extra, Uncut Edges and Gilt Tops, $7 50.

TENNYSON'S COMPLETE POEMS. The Complete Poetical Works of Alfred, Lord Tennyson. With an Introductory Sketch by Anne Thackeray Ritchie. With Portraits and Illustrations. 8vo, Extra Cloth, Bevelled, Gilt Edges, $2 50.

LEA'S HISTORY OF THE INQUISITION. History of the Inquisition of the Middle Ages. By Henry Charles Lea. Three Volumes. 8vo, Cloth, Uncut Edges and Gilt Tops, $3 00 per vol.

FLAMMARION'S ATMOSPHERE. Translated from the French of Camille Flammarion. With 10 Chromo-Lithographs and 86 Wood-cuts. 8vo, Cloth, $6 00; Half Calf, $8 25.

uka
pes